RECEIVED
MAY 29 1934
U.S. Department of Agriculture

# The EMPIRE JOURNAL of EXPERIMENTAL AGRICULTURE

VOLUME II No. 6 APRIL 1934

## CONTENTS

**O. T. Faulkner** : Some Experiments with Leguminous Crops at Ibadan, Southern Nigeria, 1925–33 . . . . . 93

**P. E. Turner:** Studies on Sugar-cane and Sugar-cane Soils. Pt. II. The Immediate and Residual Effects of Organic Manures on Crop-yield : 'Pen' Manure in Comparison with Inorganic Manures . . . . . 103

**F. T. Shutt** and **S. N. Hamilton** : The Quality of Wheat as Influenced by Environment . 119

**J. Hunter-Smith** : Changes and Events in a Large Dairy Herd from 1912 to 1932 . . 139

**A. H. Lewis** and **K. J. Sinclair** : Investigations of the Manurial Effectiveness of Ammonium Phosphate. Pt. I. Introductory and Historical . 154

**W. G. Ogg** and **I. M. Robertson** : The Reclamation of Moorland . . . . . 163

**F. Yates** and **D. J. Watson** : Observer's Bias in Sampling-Observations on Wheat . . . 174

**W. Morley Davies** and **G. Owen** : Soil Survey of North Shropshire. Pt. I. Geography, Geology, Parent Materials, Soils. With Plate 3 . . 178

OXFORD
AT THE CLARENDON PRESS : 1934

# THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE


## EDITORIAL BOARD

**Sir E. J. RUSSELL**, Rothamsted Experimental Station, Harpenden (*Chairman*).
**Sir R. H. BIFFEN**, School of Agriculture, Cambridge.
**J. M. CAIE**, Dept. of Agriculture for Scotland, Edinburgh.
**Prof. F. L. ENGLEDOW**, School of Agriculture, Cambridge.
**Sir A. D. HALL**, John Innes Horticultural Institution, Merton Park, London, S.W. 19.
**C. BRYNER JONES**, Ministry of Agriculture, Welsh Dept., Aberystwyth.
**H. J. PAGE**, Agricultural Research Station, Jealott's Hill, Bracknell, Berks.
**Prof. J. A. S. WATSON**, School of Rural Economy, Oxford.

(*The above constitute the Executive Committee*)

**Dr. E. S. ARCHIBALD**, Central Experimental Farm, Ottawa, Canada.
**B. C. BURT**, Imperial Council for Agricultural Research, New Delhi, India.
**A. H. COCKAYNE**, Plant Research Station, Palmerston North, New Zealand.
**Dr. C. CROWTHER**, Harper-Adams Agricultural College, Newport, Salop.
**Dr. H. J. DENHAM**, Institute of Agricultural Engineering, Oxford.
**Dr. I. ELAZARI-VOLCANI**, Agricultural Experiment Station, Rehoboth, Palestine.
**Sir G. EVANS**, Imperial College of Tropical Agriculture, Trinidad.
**Sir R. B. GREIG**, Dept. of Agriculture for Scotland, Edinburgh.
**Prof. J. A. HANLEY**, Armstrong College, Newcastle-on-Tyne.
**Prof. J. HENDRICK**, Marischal College, Aberdeen.
**R. HEWISON**, Sudan Plantations Syndicate, Barakat, Sudan.
**J. M. ADAMS**, Dept. of Agriculture, Dublin, I.F.S.
**Sir F. W. KEEBLE**, Hamels, Boar's Hill, Oxford.
**Dr. B. A. KEEN**, Rothamsted Experimental Station, Harpenden.
**W. NOWELL**, East African Agricultural Research Station, Amani, Tanganyika.
**Dr. J. B. ORR**, Rowett Institute, Aberdeen.
**Col. A. OLVER**, Imperial Council for Agricultural Research, New Delhi, India.
**C. S. ORWIN**, Agricultural Economics Research Institute, Oxford.
**Dr. I. B. POLE EVANS**, Dept. of Agriculture, Pretoria, South Africa.
**Dr. A. E. V. RICHARDSON**, Waite Agric. Research Inst., Glen Osmond, South Australia.
**Dr. G. SCOTT ROBERTSON**, Ministry of Agriculture, Northern Ireland.
**Prof. R. G. STAPLEDON**, Welsh Plant Breeding Station, Aberystwyth.
**F. A. STOCKDALE**, The Colonial Office, London.
**Prof. R. G. WHITE**, University College of North Wales, Bangor.

*Secretary and General Editor*
**Dr. E. H. TRIPP**, 40 Trewsbury Road, Sydenham, London, S.E. 26.


## NOTICE TO CONTRIBUTORS

**Papers submitted for insertion should be sent to Dr. E. H. Tripp, 40 Trewsbury Road, Sydenham, London, S.E. 26, but authors residing overseas should, where possible, send their papers through the local member of the Editorial Board; they should also name agents in Britain to whom proofs, &c., may be referred.**

**Authors are asked to submit their papers finished in all details, in typescript with double-line spacing, and with ample margins. Illustrations should if possible be drawn, about twice the size of the finished block, on smooth, white Bristol board in Indian ink, with marginal lettering inserted in pencil. Their order and approximate position in the text should be marked. The length of papers, including tabular matter and illustrations, should not exceed the equivalent of 5,000 words.**

**The address to which proofs are to be sent should be written on the paper and, when returning corrected proofs to Dr. Tripp, authors should state whether they desire to purchase additional offprints. Twenty-five offprints are allowed free of charge.**


*The Journal is published four times yearly by Mr. Humphrey Milford, Oxford University Press, Amen House, Warwick Square, London, E.C. 4, to whom subscriptions and all communications, other than editorial, should be addressed.*

**ANNUAL SUBSCRIPTION 20*s.* POST FREE ; SINGLE NUMBERS 7*s.* 6*d.* net.**

# SOME EXPERIMENTS WITH LEGUMINOUS CROPS AT IBADAN, SOUTHERN NIGERIA, 1925–33

O. T. FAULKNER

An extensive series of experiments has been carried out at Ibadan, in southern Nigeria, in green-manuring and into the effect of leguminous crops on later crops. The primary object of the experiments was to study whether it is possible, by the inclusion of a sufficient number of leguminous crops in a rotation, to maintain land constantly at a high level of fertility.

The rainy season at Ibadan lasts from late March until well into November. The dry season is more marked than in a typical tropical climate; its severity is indicated by the fact that cacao flourishes in the bottoms of the valleys or even on good soil on the flat, but cannot be grown on the tops of the ridges in undulating country. The experiments have shown that in these particular conditions, where two crops can be grown each year, fertility can be maintained if, annually, one of the two crops is a leguminous or green-manure crop and only one is exhaustive; provided, of course, that reasonably good covers of the leguminous crop are obtained; and provided also that no serious losses are incurred by exposing the soil, unprotected by a crop, to the leaching and erosion caused by tropical rains. This aspect of our work is mainly of local importance: more detailed information will be found in a departmental bulletin.[1] In the present paper it is proposed to deal with some facts of more general interest that have emerged from these investigations.

Prevailing ideas about green-manuring may perhaps be expressed roughly as follows: a green manure is a crop which is grown to improve the land, and which, instead of being harvested in the ordinary way, is turned into the soil in order to enrich it with the nitrogen and organic matter resulting from the decomposition of the material thus buried. Further, in discussions about this subject, considerable emphasis is generally laid upon the necessity for turning in the material when green, before any seed is produced; and on turning it in without delay into a moist soil, so as to encourage rapid decomposition. Indeed, it is sometimes even suggested that the success or failure of green-manuring, as judged by the effect on the following crop, may depend entirely on the condition of the green-manure crop and of the soil when the burying takes place. It seems also to be inferred that the improvement of the land which results from green-manuring persists for a considerable time and influences the yield of several succeeding crops. These are the ideas that one gathers from the literature about green-manuring, and presumably they represent the results of accumulated experience and experiments in temperate climates. When the Ibadan experiments were started in 1922, it was not doubted but that these principles would also be found to be roughly applicable to green-manuring in the tropics. Only in the

[1] *The Maintenance of Soil Fertility in Southern Nigeria*, by C. J. Lewin, obtainable from Director of Agriculture, Ibadan (price 2*s.* 6*d.*).

course of years have we come to believe that not one of the series of general ideas expressed or implied in the above description of green-manuring holds good in our local conditions. As a result of field experiments we have now reached the conclusion that, so far as concerns the succeeding crop, the only really important points about a fertility-maintaining crop are:

(*a*) that it should be one that has proved highly effective in actual trials; and
(*b*) that the straw or haulms should not be totally removed from the field.

We find that it makes little difference whether the crop is buried at the proper stage of growth or is allowed to produce its seed; whether it is buried green or allowed to remain on the surface of the soil through our three months of dry weather and then buried in a desiccated state; or even whether it is burnt *in situ*. Again, we find that the benefit from green-manuring in our conditions is largely exhausted by the next succeeding crop. Indeed, partly as a result of experiments and partly as a result of our ten years' practical experience of green-manuring, we now regard the after-effect of a green-manure crop, not as something rather similar to that of organic manure in a temperate climate, but rather as similar to that of soluble 'artificials'. It must be emphasized that these statements are believed to apply only to a strictly tropical climate. For instance, even in the more northerly parts of Nigeria, where the climate is nearer to the typical sub-tropical one than to the tropical, green manure, in the few trials made, has been found to be much more lasting in its effects than at Ibadan.

The general nature of the soils at Moor Plantation and in its neighbourhood has already been explained.[1] The soils at Ibadan generally contain 50–70 per cent. coarse sand, 10–30 per cent. fine sand, and about 20 per cent. silt and clay together. They generally contain less than 0·15 per cent. total nitrogen, and have a pH value between 5·7 and 6·7. It may, however, be said at once that there has been no indication that the results of these experiments depend closely on the type of soil used, provided only that the land is capable of growing the green-manure crop at all; but naturally the experiments have no bearing on swamp rice-land. The results of green-manuring on the highly acid soils of the south-east of Nigeria (pH about 5·2 or less) have so far been most disappointing; but the failure has always been explicable by the fact that the green-manure crop itself was a failure. Very similar results to those at Ibadan were obtained when the experiments were repeated at Ilorin, where the land, though different from that at Ibadan, also grows legumes well.

The first clear indication that our ideas about green-manuring in this climate needed radical modification arose from the results of a series of nine plots (C. 5N 11–19). On all these plots in each year since 1925, a crop of *Mucuna utilis* has been grown and cut in early November; on

[1] *Soil-formation in Southern Nigeria*, by H. C. Doyne and W. A. Watson, *J. Agric. Sci.*, 1933, **23**, 208–15.

the five odd-numbered plots it is dug in at once, i.e. on the same or the following day; but on the four even-numbered plots the *Mucuna*, having been cut, is allowed to remain lying on the land from early November till early March, and is then dug in. In November the *Mucuna* has hardly begun to form seed, the soil is thoroughly moist, the weather still damp, the cut material soft and green and easily decomposable. During the four months that the cut plants remain on the surface of the even-numbered plots, there is little or no rain (2 or 3 inches at most, sometimes none) and the air becomes intensely dry. The material that is buried is thus thoroughly dry, and it is dug into a thoroughly dry soil; on these plots the process can hardly be called 'green-manuring' at all. The *Mucuna* is followed by maize in the early part of the next season. The results have been as follows:[1]

C. 5N 11–19.

| | *Mean yield per acre of maize on 5 plots dug in early November (lb. per acre)* | *Average difference of yield of 4 plots cut November, dug in early March (lb. per acre)* |
|---|---|---|
| 1926 . . . | 2,269 | − 22±122 |
| 1927 . . . | 1,631 | −169±128 |
| 1928 . . . | 1,908 | −102±112 |
| 1929 . . . | 1,914 | −145±144 |
| 1930 . . . | 1,901 | −193± 29 |
| 1931 . . . | 1,957 | −232± 60 |
| 1932 . . . | 1,452 | − 84± 81 |
| 1933 . . . | 798 | + 42± 32 |

It will be seen that in the first year the difference was negligible. The crop of 1933 was a partial failure all over the farm and neighbourhood, owing to a long drought when the crop should have been growing, followed by exceptional rains when the crop was setting and ripening. Little importance can be attached to the exceptional result in that abnormal year. Neglecting 1933, the results seem to indicate, on the

[1] All the experiments mentioned in this paper are arranged in the same way. The length of the plots is ten times the width and they adjoin by their long sides. Every alternate plot is a control ('standard treatment') plot; the yield of each experimental plot is compared to the average of the two control plots lying on each side of it (i.e. yield of plot 2 is compared with the average of the yields of plots 1 and 3); and the differences thus obtained for each treatment as compared to the standard are averaged. The figures after the ± sign are calculated as follows: the root of the mean squared differences between the $n_1$ pairs of control plots is calculated $\left(\sqrt{\frac{\sum d^2}{n_1}}\right)$, using all the alternate pairs, i.e. the difference between the yields of plots 1 and 3 is $d_1$ and that between plots 3 and 5 is $d_2$. The standard error given against each average result is this figure divided by $\sqrt{n_2}$ $\left(\text{i.e. } \sqrt{\frac{\sum d^2}{n_1 n_2}}\right)$ where $n_2$ is the number of plots receiving that particular treatment. Theoretically perhaps $\sqrt{\frac{3\sum d^2}{4n_2(n_1-1)}}$ would be a more correct formula, and the rough estimates of standard errors which are given in this paper thus tend to be over-estimates rather than the reverse.

whole, a definitely superior result from 'burying green'; but the degree of superiority is never great, and is less than 10 per cent. on the average. There is no evidence that the superiority is steadily cumulative, as was anticipated when the experiment was started.

If an only slightly inferior result is obtained from cutting the crop in November and allowing it to lie on the land till February before it is dug in, which seems a rather unpractical procedure, the question arises: would a greatly inferior result be obtained if the green-manure crop, instead of being cut in November, were allowed to complete its growth and mature before being buried in March? The material buried is then distinctly more woody than when cut in November. This point has been tested in a separate experiment with the results given below. *Mucuna* was grown in the latter part of 1925, and thereafter the rotation was early maize followed by *Mucuna* each year.

B 7 and 8.

| | *Average yield of maize on 9 plots after Mucuna, buried green in November (lb. per acre)* | *Average difference of yield of 8 plots after* Mucuna, *allowed to die and buried in March (lb. per acre)* |
|---|---|---|
| 1926 . . . | 2,308 | $-102 \pm 90$ |
| 1927 . . . | 1,652 | $-\ 60 \pm 59$ |
| 1928 . . . | 1,903 | $-\ 86 \pm 50$ |
| 1929 . . . | 1,974 | $-121 \pm 54$ |
| 1930 . . . | 2,292 | $-211 \pm 63$ |

Again the result of burying dry material in March proves inferior to that from burying green material in November, but again the inferiority is slight, little or no greater, in fact, than that from cutting in November and leaving the young material on the surface of the land until spring.

On the other half of the field C. 5N, on which the experiment first mentioned in this paper is carried out, there is a series of plots in which the alternate controls are treated exactly in the same way as the four experimental plots in that experiment, except that the green-manure crop, having been cut in November, is burnt at the end of February just before the land is dug in early March. The four 'cut and dried' plots in the experiment on the one half of the field can thus be compared with the five 'burnt' plots on the other; and though no significance at all can be attached to any difference observed in the first year, yet the change, or absence of change, in the relative average yields of the two series of plots is instructive (for results see table on next page).

It still appears doubtful if there is any increasing inferiority in the yield from the burnt plots, although nothing but ash has been returned to them for eight years. The more probable explanation of the figures in the last column would seem to be that the side of the field carrying the burnt plots was inherently a little less fertile than the other, and that the variation of the figure in the last column from year to year is merely a normal fluctuation around a natural difference of unknown degree which would have been observed even if both sides had been exactly similarly treated. The figures do not justify any conclusion about the immediate

C. 5N 2–19.

| | *Average yield of 4 plots 'cut and dried', dug early March (lb. per acre)* | *Average yield of 5 plots burnt and dug early March (lb. per acre)* | *Difference in average yield (lb. per acre)* |
|---|---|---|---|
| 1926 . . . . | 2,241 | 2,098 | −143 |
| 1927 . . . . | 1,497 | 1,523 | + 26 |
| 1928 . . . . | 1,791 | 1,622 | −169 |
| 1929 . . . . | 1,761 | 1,741 | − 20 |
| 1930 . . . . | 1,710 | 1,605 | −105 |
| 1931 . . . . | 1,714 | 1,820 | +106 |
| 1932 . . . . | 1,360 | 1,331 | − 29 |
| 1933 . . . . | 829 | 690 | −139 |

effect of burning, only about its cumulative effect. One cannot help feeling that to continue to burn the aerial portion of the green-manure crop year after year must eventually lead to a gradual decline of fertility, however satisfactory the process may be temporarily; but in view of the above results, it seems clear that such cumulative decline, if it is occurring at all, is very slow.

The question of whether a green-manure crop can, without loss, be burnt instead of being buried is one that is of great practical importance in southern Nigeria. We have found that, apart from the burying of green manure, there is no advantage in digging the land in preparation for any crop except yams, which respond greatly to deep preparatory digging. For other crops, the native method of scraping up loose soil on to the old hill or ridge gives as good a result as does a deep and thorough cultivation. If the green-manure crop has to be buried green, this entails deep digging; and green-manuring is then a laborious process which the farmer will adopt with reluctance or not at all. If the green-manure crop can be burnt, then green-manuring involves little labour and is a vastly more attractive process.

In 1931 three series of new experiments were therefore started in order to test thoroughly the effect of burning. The first of these three 1931 experiments is carried out on a block (B. 7 and 8) containing 17 quarter-acre plots. On all of them the rotation is late *Mucuna* followed by early maize. On 9 of the plots the *Mucuna* is cut and buried green in November; on the other 8 plots it is cut and burnt in November, and these burnt plots are then dug and ridged just the same as the others and at the same time. The results so far have been as follows:

B. 7 and 8.

| | *Average yield of maize on 9 plots,* Mucuna *dug in green (lb. per acre)* | *Average difference in yield 8 plots,* Mucuna *burnt in November (lb. per acre)* |
|---|---|---|
| 1932 . . . | 1,615 | +90± 103 |
| 1933 . . . | 697 | +84± 31 |

A second similar series (A. 5S) of 19 quarter-acre plots is located upon very poor gravelly soil. Again the treatment is carried out in November, but on four of the plots the *Mucuna*, instead of being buried or burnt, is carried off the field and disposed of elsewhere. As far as possible, the roots are removed from these plots as well as the aerial parts of the green crop. The results have been as follows:

A. 5S.

| | *Average yield of maize on 10 plots,* Mucuna *dug in green (lb. per acre)* | *Average difference on 5 plots,* Mucuna *cut and burnt in November (lb. per acre)* | *Average difference on 4 plots,* Mucuna *pulled November and carried off* |
|---|---|---|---|
| 1932 . . . | 946 | − 4±83 | −169±92 |
| 1933 . . . | 375 | +55±42 | −112±47 |

In the third series (C. 3W), the *Mucuna* on the ten control plots is allowed to grow on until February, by which time seed is set and the crop has died off almost completely. On three of the experimental plots the green manure is cut in November and allowed to dry on the soil until February, when it is dug in; on three plots it is burnt in February; from three, the aerial parts of the crop, but not the roots, are carried away completely. No seed is harvested from any plot. The results have been as follows:

C. 3W.

| | *Average yield of 10 plots of maize, whole crop of* Mucuna *buried in February (lb. per acre)* | *Average difference on 3 plots,* Mucuna *cut in November, buried in February (lb. per acre)* | *Average difference on 3 plots,* Mucuna *allowed to mature and burnt (lb. per acre)* | *Average difference on 3 plots,* Mucuna *allowed to mature and carried off (lb. per acre)* |
|---|---|---|---|---|
| 1932 | 1,163 | +148±150 | +277±150 | −191±150 |
| 1933 | 717 | − 9±123 | +131±123 | −144±123 |

Burning in November (in the first two experiments) appears slightly superior to burying the green crop in November, and burning in February (in the last experiment) is superior to burying either a mature or a dried crop at the same time. (The rather smaller difference observed in the first experiment as compared with that in the third is consistent with the previously observed superiority of burying green in November over any other process except burning.) Complete removal of the crop, whether in November or February, causes an immediate diminution of the yield of the succeeding maize crop. The decrease, however, even from the complete removal of all the aerial parts of the green-manure crop and so much of the roots as it is practical to remove in a field-experiment, is only 150 or 200 lb. per acre at most, and is much the same as the increase that results from burying the material green in November instead of letting it mature naturally or dry (after cutting) during the period November–February. Yet the gross increase in the early maize

crop, which results at Ibadan from growing a preceding leguminous crop, is known to be of the order, not of 150 or 200 lb. per acre, but of 600 or 800 lb. (see, for instance, the rotation experiment quoted later in this paper). It is suggested, therefore, that there may be two quite separate main factors concerned in the effect of a green-manure crop on a succeeding crop of maize; the greater of these factors causes an increase of something like 400 to 600 lb. in a succeeding early-maize crop, even if the parts of the green-manure crop above ground are carried away. It is suggested that this factor is a stimulus to nitrification in the soil, which is caused either by the growing leguminous crop or by the decomposition of nodules and very small roots which cannot easily be removed from the soil on a field scale, as is attempted in one of the experiments above. It is suggested that the other factor is the mineral plant-food constituents which are contained in the leaves and stems of the green manure; and that these become available for the succeeding crops to a much greater extent if the crop is burnt or buried green than if it is buried after it has matured or dried. This factor seems to cause an increase at best of something like 200 lb. per acre in a succeeding maize crop. It is suggested that the addition to the soil of the carbonaceous and nitrogenous organic matter in the parts of the green-manure crop above ground does not play an important part in effecting the increase of yield that results in the succeeding crop. Pending fuller investigation of the question, these ideas are put forward merely as an hypothesis that fits all the facts observed as yet. It is obviously no more than that; and possibly other hypotheses could be propounded which would be equally plausible.

If the aerial parts of a green-manure crop can be burnt without a loss of yield in the succeeding crop, the question arises whether harvesting the leguminous seed before burning the crop will result in much loss: for the loss of mineral constituents through harvesting is not very heavy. An experiment bearing on this question was started in 1932. In that year, on ten quarter-acre plots (A. 5N), *Mucuna* was dug in green in November, so that the process could truly be called green-manuring. On the alternate plots, 'Selected Popondo'—a pure-line selection of a local variety of *Phaseolus lunatus*—was allowed to ripen its seed in December and January, before being burnt, and the plots were ridged like the others. An average yield of 550 lb. per acre of shelled beans (912 lb. unshelled) was harvested from the Popondo plots and the results on the succeeding maize crop were as follows:

A. 5N.

| | *Average yield of maize on 10 plots after* Mucuna *dug in green (lb. per acre)* | *Average yield on 9 plots after* Popondo *harvested and burnt (lb. per acre)* |
|---|---|---|
| 1933 . . | 597 | +53±33 |

Apart from the unfortunate fact that 1933 was a very bad season for early maize, this experiment is obviously open to the theoretical objection that it may only mean that Popondo is specifically much superior to *Mucuna* as an improver of fertility, and that this superiority is too great

to be entirely offset by the loss resulting from harvesting its seed: or, alternatively, that the process of burning a mature crop in February is so greatly superior to burying a green crop in November, that the difference is not entirely offset by the adverse effect of harvesting the seed. In a practical sense, however, the experiment shows that the seed can be harvested from a green-manure crop without any serious diminution of its value as a fertilizer, provided that the bean that is grown is one that is an efficient soil fertilizer, and provided that after harvest the straw of the bean crop is burnt on the land.

The question may well be asked: 'If this is true, to grow and harvest a crop of field beans in England should be as valuable as green-manuring for improving the soil for succeeding crops?' The cases are, of course, far from being strictly parallel. For one thing, the Popondo yielded a harvest of a quarter of a ton of beans per acre, while the field beans yield a ton or more of seed.

There are yet other aspects of the question, about which our views have totally changed as a result of twelve years of experiments and experience. At first it was naturally imagined that, provided it was dug in green before it seeded, a green manure that was allowed to grow for six months would result in a much greater improvement of the fertility of the soil, perhaps roughly twice as great, than a similar crop which grew for only three months. We now believe that, provided the leguminous crop reaches the stage where it makes a heavy cover, little is gained (or, incidentally, lost) by leaving it to grow for a longer time. Naturally it is quite useless to bury or burn small leguminous plants which but partly cover the land and weigh a few hundred pounds per acre in the green state; but it does not seem to matter how long the crop is on the land, provided that it grows long enough to make a heavy cover. Quick-growing crops that soon cover the soil and soon produce a heavy aerial growth are not only the most practical and economical green manures for use in a rotation on arable land; but they also seem to be fully as effective in increasing fertility as are crops which occupy the land for a whole year or more. Further, as already mentioned, we have also reached the conclusion that at Ibadan (not everywhere) green-manuring has only a small residual effect on later crops after the one which immediately follows it.

It is difficult to design a 'critical' field experiment to test such theories. For instance, it is difficult even to test directly, in the field, the comparative effects of 'green manure' and 'no green manure' on succeeding crops; for while one series of plots is growing the green-manure crop, the other must grow something. If it is kept bare, then the result which is eventually measured may well represent, not so much the benefit of green-manuring, as the loss from allowing the control plots to be leached and eroded by tropical rain. Much the same applies to 'long season' and 'short season' green manure. The conclusions which have been mentioned above are, in fact, based on the results of many experiments in which different rotations are compared. Considerations of space forbid detailed explanation here of all these rotation experiments; and, for the reasons mentioned, no single one of these experiments could alone justify the conclusions which we have drawn from the whole. The following

experiment is selected for description here because it is as nearly a 'critical' experiment of this type as we have been able to devise:

| | *10 Odd-numbered Plots* | *9 Even-numbered Plots* |
|---|---|---|
| 1927 . . | *Mucuna* and cotton | *Mucuna* and cotton |
| 1928 . . | *Mucuna*<br>Late maize 1,139 lb. | Early maize 1,290 lb.<br>Late maize $-545 \pm 15$ lb. |
| 1929 . . | Early maize 1,094 lb.<br>*Mucuna* | *Mucuna*<br>*Mucuna* |
| 1930 . . | Yams 10,901 lb.<br>Cotton 389 lb. | Yams $-956 \pm 326$ lb.<br>Cotton $-52 \pm 15$ lb. |

The yield of yams in the last year of the experiment, the yield of the cotton interplanted in the yams, and the yield of the late maize on the odd-numbered plots in 1928 are all good. For instance something between 8,000 and 9,000 lb. per acre, gross, is generally the average yield of yams on the whole of Moor Plantation, and the average yield of late maize seldom exceeds 1,200 lb.; in 1928 it was 1,090 lb. These figures show that the land used for this experiment was of normal general fertility, as judged by local standards. Yet the yields of 1,290 lb. of early maize on the even-numbered plots in 1928 and of 1,094 lb. on the odd plots in 1929 are very poor. The average yield for the whole farm is generally around 1,900 lb. per acre, and in each of those two years, 1928 and 1929, the actual figure was 1,920 lb. per acre (by chance exactly the same in each year). The poor yields from these two crops—630 lb. per acre and 836 lb. per acre below average—were undoubtedly due to the fact that, unlike every other early maize crop on the farm in those years, they did not immediately follow a legume, but only benefited from any such residual effect as may remain from a leguminous crop after one exhaustive crop has been taken. Such residual effect is clearly not great. The loss of late maize—545 lb. per acre in 1928—as a result of following early maize instead of green manure is relatively, at least, even greater; for late maize at Ibadan yields only about 70 per cent. of the yield of early maize on similar land.

In 1930 the yams and cotton on the odd plots, where they followed a whole season's *Mucuna*, actually yielded slightly, but significantly, less than on the odd plots, where they followed only a late, short, *Mucuna* crop. This result was hardly to be expected, for the longer-season crop had not matured entirely; but at all events, it makes it quite clear that the long-season green-manure crop was not more effective than the short one.

To summarize, therefore, we find that at Ibadan a green-manure crop need only occupy the land long enough to make a heavy growth; that burning is not only the most convenient, but also the best method of disposing of the crop, as judged by the effect on the yield of a succeeding crop; that complete removal of the parts of the green-manure crop above ground reduces, but is far from wholly preventing, the benefit that results in the crop that follows a leguminous one. On the other hand, whatever be the method of disposal of the green-manure crop, comparatively little benefit remains after one exhaustive crop has succeeded it. It must again be emphasized that it is not suggested that these

conclusions will hold good where the conditions are dissimilar to those at Ibadan. It is believed that they may hold good elsewhere in the tropics wherever the land is light and the rainfall heavy and prolonged; but it is strongly suspected that, in several respects, almost exactly opposite conclusions would result from similar work in a dry sub-tropical climate. There is no means of judging whether these results have any significance in connexion with green-manuring in temperature climates.

*Acknowledgement*

The experiments mentioned in the paper have been carried out at Moor Plantation under a succession of agriculturists who have had charge of the farm, each for one or two seasons; and many members of the department have assisted in the planning of the experiments. The author's share of the work has been little more than writing up the conclusions.

(*Received January 23, 1934*)

# STUDIES ON SUGAR-CANE AND SUGAR-CANE SOILS

## *Pt. II.* THE IMMEDIATE AND RESIDUAL EFFECTS OF ORGANIC MANURES ON CROP YIELD: 'PEN' MANURE IN COMPARISON WITH INORGANIC MANURES

P. E. TURNER

(*Soil Chemist to the Sugar-cane Investigation Committee of Trinidad; Imperial College of Tropical Agriculture, Trinidad, B.W.I.*)

THE immediate and residual effects of dressings of lime on yields of sugar-cane were discussed in the first paper of this series [1]. In the present paper an account is given of the immediate and residual effects of plantation 'pen' manure on yield. Consideration is also given to the relative merits of pen manure and inorganic manures, and to the type of result which is obtained when the two classes of manure are used in combination. Pen manure is also compared with other organic manures.

### I. *Preparation and Composition of Pen Manure*

Pen manure is much used as a manure for sugar-cane in the British West Indies and Mauritius. In many important sugar-producing countries, such as Cuba, Hawaii, Puerto Rico, and the Philippines, its value is not considered to justify the expenditure incurred in its manufacture.

There is no standardized method of making pen manure. The basal material commonly used as bedding for the live stock consists of trash, i.e. the leaves and other portions of the cane-plant which are not put through the mills, but are left in the field during harvesting operations. Coarse grasses from waste areas may also be used. It has recently become customary to deposit spare bagasse[1] in the stock pens. The construction of the pens permits of the accumulation of a large bulk of material, and additional supplies are transported to them from time to time, as convenience permits, until no more room is available. Waste products from the factory, such as the muds from the filter-presses, sludge from the distilleries, and molasses may also be added to assist in wetting the bedding, to increase its content of nitrogen, potash, and phosphate, and to facilitate decomposition. The length of time during which the bedding remains in the stock-pens is determined by the demand for manure in the field; the maximum time is about eight or nine months. The output of manure in a year for each head of cattle varies from plantation to plantation; in Trinidad the limiting amounts lie between 8 and 50 tons, although it has been stated [2] that as much as 100 tons can be prepared.

Analyses of seven characteristic specimens of pen manure are recorded in Table 1. The determinations were made immediately after sampling. The annual output of manure for each head of cattle from pen A is

[1] Bagasse (alternatively megasse) is the fibrous residue remaining after the juice is extracted from the cane. It is usually burned as fuel in the factory furnaces.

8 tons; from pen B between 12 and 15 tons; from pens C, D, and E approximately 30 tons; and from pens F and G over 40 tons.

TABLE 1. *Analysis of Typical Samples of Trinidad Pen Manure*

(G. Rodriguez and L. A. M. Potter)

| *Pen* | *Moisture* | *Organic matter* | *N* | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|
| A | 71·9 | 19·2 | 0·47 | 0·42 | 0·30 |
| B | 72·7 | 19·3 | 0·43 | 0·98 | 0·19 |
| C | 71·3 | 14·5 | 0·44 | 0·32 | 0·26 |
| D | 76·2 | 15·6 | 0·45 | 0·57 | 0·16 |
| E | 78·5 | 15·4 | 0·38 | 0·56 | 0·19 |
| F | 74·2 | 17·9 | 0·18 | .. | .. |
| G | 78·0 | 18·2 | 0·22 | .. | .. |
| Average | 74·7 | 17·2 | 0·37 | 0·57 | 0·22 |
| English F.Y.M. | 76·0 | 18·0 | 0·62 | 0·33 | 0·25 |

The seven samples were fairly uniform in regard to content of organic matter, but they appeared to vary greatly in degree of humification.

According to the data in Table 1, the amount of nitrogen in pen manure remains fairly constant provided that the unit output is not greater than 30 tons. When this figure is exceeded the amount of nitrogen appears to fall off rapidly. Deerr [3] states that the nitrogen in pen manure usually ranges from 0·6 to 0·8 per cent., when the unit quantity produced lies between 15 and 20 tons; the average value in Trinidad is 0·45 per cent. for an output not exceeding 15 tons. Deerr mentions that the value for nitrogen may fall to 0·5 per cent., or even 0·3 per cent. when an excess of bedding is placed in the pens. Even when a minimum amount of litter is used (Pen A, Table 1), the amount of nitrogen in Trinidad pen manure does not reach 0·5 per cent.

The maximum and minimum values for potash in Trinidad pen manure are 1·0 and 0·3 per cent., respectively. The corresponding figures for phosphate are 0·3 and 0·16 per cent. In both cases the variation probably depends on the nature and amount of the material used for wetting the bedding. It appears to be independent of the amount of bedding used. Deerr [3] quotes 0·7 and 0·2 per cent. as limiting values for both potash and phosphate.

## II. *Effect of Pen Manure on Yield of Cane*

At one time it was customary in certain areas to base the manurial treatment of sugar-cane almost entirely on pen manure. It was the general aim to apply to the acre of plant-canes not less than 20 tons[1] of this manure. The head of stock normally maintained on a sugar plantation for transport and general purposes is inadequate to supply so much pen manure; consequently there was a well-defined policy to augment supplies by increasing the head of stock above that required for working

[1] In some West Indian islands endeavour is still made to apply regularly to plant-canes dressings as large as 40 tons of pen manure to the acre.

purposes [4]. The information then available in the literature of sugar-cane was too scanty to enable a comparison of the cost of preparing pen manure with the gain in yield resulting from its use. Field-experiments were therefore laid down to secure the necessary data.

(*a*) *Effect of increasing doses of pen manure on yield of a complete crop series of hardy canes.*—An immediate aim of the first of these experiments was to determine the effect on yield of different dressings of pen manure. The amounts of manure per acre selected were: (i) none, (ii) a unit dressing of 10 tons, (iii) a double dressing of 20 tons, and (iv) a triple dressing of 30 tons. A dressing of 10 tons was selected as the unit treatment because pen manure can be prepared on most plantations, by the use of working cattle alone, in amount adequate to supply the whole area under plant-canes at this rate. The double application of 20 tons to the acre corresponds to the application in general use at the time. The triple dressing corresponds to the maximum application then in actual use in Trinidad.

At the time a critical comparison of the relative value of plantation pen manure and an inorganic manure had not been made. The scope of the experiment was therefore extended to include a fifth treatment, comprising nitrogen, potash, and phosphate in inorganic form. The results given by the organic and inorganic manures are compared later in this paper. The present section deals with pen manure alone.

It was recognized that the effect of pen manure on yield might be seen in the ratoon-crops as well as in the plant-canes. To obtain precise information on this point the experiment was continued for five years, the plant-canes and the first, second, and third ratoons being harvested. No manurial treatments were applied to the ratoon-canes. The yield-data for the complete crop series are recorded in Table 2.[1]

Curves of diminishing returns are obtained when the increment in yield of plant-canes, and of the first, second, and third ratoons, are plotted against quantity of pen manure (Fig. 1, page 107). Maximum yield is not reached even with the dressing of 30 tons of pen manure to the acre. It is of interest that Saint [5] has since found that no additional gain in yield results when pen manure is applied in amount larger than 10–15 tons to the acre on the more fertile soils of Barbados.

The immediate effect of treatment with pen manure on the yield of plant-canes, and the residual effects on the first and second ratoons, might be due to chance less than once in 100 times. The residual effect on the third ratoons might be due to chance less than once in 20 times. It may therefore be regarded as established that the influence of a single application of pen manure on yield can extend over four successive crops.

The four increments for plant, first, second, and third ratoon-canes are approximately in the ratio 4: 3: 2: 1, indicating that in this experiment there was a fairly regular diminution in the average increment from crop to crop. The residual increment of 1·53 tons for the fourth crop (the third ratoon-canes) is approximately equal to the annual average

[1] Yield data for plant-canes, first and second ratoons in this and certain of the following tables have been published previously in *Tropical Agriculture*, 1933, **10**.—Edit.

diminution in yield of 1·74 tons. It is highly probable, therefore, that the residual gain in yield ceases to be measurable from this stage onwards.

TABLE 2. *Immediate and Residual Effects on Yield of a Complete Crop Series of Sugar-cane of an Inorganic Manure and Increasing Doses of Pen Manure*

Cane variety: Uba
Soil type: Raw clay
Lay-out: Two 5 × 5 Latin squares

*Expt. I*

| *Manurial treatment as plant-canes per acre* | *Yield (tons cane per acre)* | | | | | |
|---|---|---|---|---|---|---|
| | *Plants* | *First ratoons* | *Second ratoons* | *Third ratoons* | *Crop series* | *Total gain* |
| None | 24·75 | 15·64 | 13·16 | 12·45 | 66·00 | .. |
| 10 tons pen manure | 29·40 | 18·30 | 15·19 | 13·73 | 76·62 | 10·62 |
| 20 tons pen manure | 31·35 | 20·70 | 16·24 | 14·03 | 82·32 | 16·32 |
| 30 tons pen manure | 33·75 | 21·49 | 17·10 | 14·18 | 86·52 | 20·52 |
| Complete inorganic manure | 33·94 | 21·075 | 14·475 | 12·94 | 82·43 | 16·43 |
| Average increment due to pen manure | 6·75 | 4·52 | 3·01 | 1·53 | 15·81 | .. |
| Diminution in average increment | .. | 2·23 | 1·51 | 1·48 | .. | .. |
| Increment due to inorganic manure | 9·19 | 5·43 | 1·31 | 0·49 | 16·43 | .. |
| Diminution in increment | .. | 3·76 | 4·12 | 0·82 | .. | .. |

The experiment was laid down in the form of two 5 × 5 Latin squares on a heavy, raw clay soil of pH value 5·0–5·5. The experimental area was planted in Uba cane. This is a hardy variety of cane, which can give good yields both of plants and ratoons on soils unsuited to noble canes, such as the variety B.H. 10 (12). The sample of pen manure applied to the experimental area was of average quality and typical of that in general use.

In this experiment the total residual increment in yield of 9·06 tons of cane, for the three ratoon crops, is definitely in excess of the immediate increment of 6·75 tons of plant-canes.

(*b*) *Optimum dressing of pen manure.*—The costings data for Expt. I are sufficiently important to be recorded, and accordingly the net financial gains resulting from the various treatments are summarized in Table 3. In preparing this table due allowance was made for the expenditure entailed in manufacturing, transporting, and applying the manure, and in reaping the increased tonnage resulting from manuring. Detailed information with regard to the methods of costing is given elsewhere [4].

TABLE 3. *Relationship between Size of Dressing of Pen Manure and Net Financial Gain for a Complete Crop Series*

| *Manurial treatment per acre* | *Net gain $ per acre* |
|---|---|
| 10 tons pen manure | 13·18 |
| 20 tons pen manure | 14·07 |
| 30 tons pen manure | 10·91 |
| Complete inorganic manure | 24·70 |

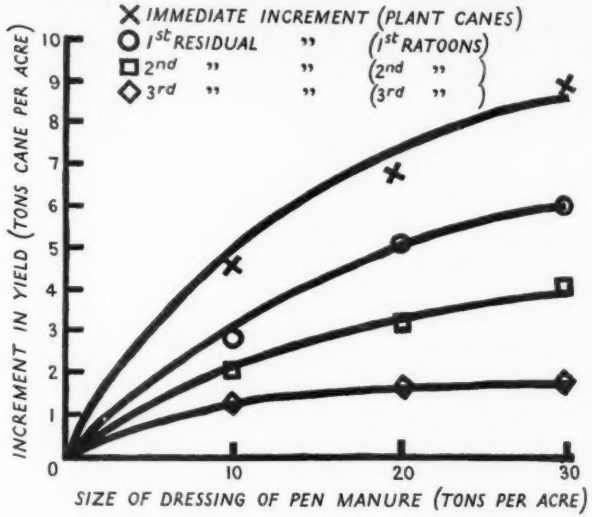


FIG. 1. Immediate and residual effects of single dressings of pen manure on yield of Uba canes.

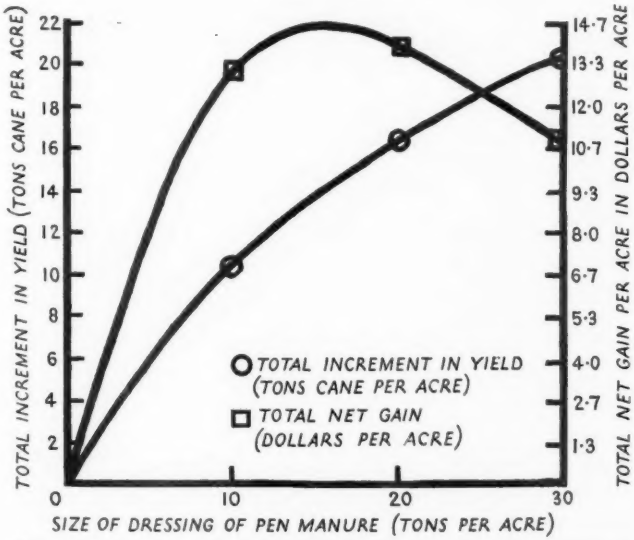


FIG. 2. Effect of size of dressing of pen manure on total increment in yield and total net gain to the acre, plant and ratoon Uba canes.

In Fig. 2 the size of dressing of pen manure is plotted against the total increments in yield for the crop series, and against the net financial gain which results from these increments. The two curves differ in that the former does not attain a maximum within the range of the treatments applied, whereas the latter rises to a maximum and subsequently falls. Both rise and fall in the costings curve are definitely significant, and might be due to chance less than once in 100 times.

According to Fig. 2 the dressing of pen manure which gives maximum financial gain lies in the region of 15 tons to the acre. When amounts larger than 15 tons are used, the cost of preparing and carting the manure more than counteracts the value of any additional increments in yield. The slope of the costings curve falls off appreciably between the dressings of 10 and 15 tons of manure. Consequently the additional gain derived by using more than 10 tons is small. Therefore, under the conditions which obtain, it appears inadvisable to maintain supplementary stock merely to augment the dressing of pen manure.

(*c*) *Effect of standard dressing of pen manure on yield of a complete crop series of noble canes.*—Experimental work in Trinidad has indicated that hardy canes of the Uba type as a rule respond more generously to manurial treatment than noble canes. The immediate and residual effects of a dressing of pen manure on a complete crop series of two varieties of noble canes, under differing soil conditions, are set out in Table 4.

TABLE 4. *Immediate and Residual Effects of Pen Manure on Yield of Noble Canes*

Lay-outs: Randomized blocks or Latin squares

| *Expt.* | *Cane variety* | *Treatment with pen manure* | *Yield of cane (tons per acre).* | | | |
|---|---|---|---|---|---|---|
| | | | *Plant-canes* | *First ratoons* | *Second ratoons* | *Crop series* |
| II | B.H. 10/12 | 20 tons | 38·59 | 23·32 | 11·79 | 73·70 |
| | | None | 33·47 | 20·92 | 10·08 | 64·47 |
| | | Gain | 5·12 | 2·40 | 1·71 | 9·23 |
| III | B. 156 | 20 tons | 39·01 | 31·33 | 11·76 | 82·10 |
| | | None | 31·87 | 28·47 | 10·70 | 71·04 |
| | | Gain | 7·14 | 2·86 | 1·06 | 11·06 |
| IV | B.H. 10/12 | 20 tons | 35·00 | 40·66 | .. | .. |
| | | None | 30·95 | 38·12 | .. | .. |
| | | Gain | 4·05 | 2·54 | .. | .. |
| II and III | Average gain | | 6·13 | 2·63 | 1·38 | 10·14 |

Expt. II was laid down on an area of soil similar in type to that of Expt. I, but with pH value lying between 6·5 and 6·8. Expt. III was laid down on the exhausted soil, of pH value 6·5, which was described in the first paper of this series [1]. Expt. IV was laid down on an area of heavy clay soil, of pH value 5·6 to 6·2. All plots in Expt. IV were given a basal dressing of a complete inorganic manure.

The immediate and first residual increments in yield in each experiment might be due to chance less than once in 100 times. The second residual increments might be due to chance less than once in 20 times. In Expts. II and III the effect of pen manure on yield has persisted over three successive crops, which constitute a complete crop series of noble canes. The residual effect on second ratoons is small; it probably ceases to be measurable at this stage in these experiments.

The immediate increment in yield, and also the first and second residual increments, are each smaller for the noble canes in Expts. II and III than for the Uba canes in Expt. I. The average gain for the complete crop series of noble canes is 10·14 tons. The corresponding gain derived from 20 tons of pen manure by the plant- and first two ratoon-crops of Uba cane is 14·74 tons. The average total residual increment in yield of the ratoon-canes in Expts. II and III (4·01 tons) is somewhat less than the average immediate increment in yield of plant-canes (6·13 tons). When the complete set of data for all three experiments are considered, the immediate gain in yield of plant-canes due to pen-manuring is roughly equal to the total residual gain in yield of the ratoon crops. Previous to these experiments the residual value of plantation pen manure was largely a matter of speculation.

The smallest immediate gain in yield, as a result of pen-manuring, was obtained in Expt. IV, when a basal dressing of a complete inorganic manure was applied. The interaction of pen manure with inorganic manures is discussed later (pp. 112–13). The largest immediate gain in yield was obtained in Expt. III, which was laid down on a soil deficient in potash. General experimental experience in Trinidad indicates that response to dressings of pen manure tends to be greatest on soils that are lacking in potash.

### III. *Pen Manure versus Inorganic Manures*

(*a*) *Increasing doses of pen manure versus an inorganic manure.*—In Table 2 data are recorded enabling the immediate and residual effects on yield of an inorganic manure to be compared with those of pen manure. The inorganic manure comprised 90 lb. of nitrogen as sulphate of ammonia, 375 lb. $P_2O_5$ as ground rock-phosphate, and 60 lb. of $K_2O$ as sulphate of potash.

The essential features of the yield data are as follows [4]:

(1) The yield of plant-canes on the inorganic plots was significantly in excess of the yield on the plots which received 10 tons of pen manure, and equal to that on the plots which received 30 tons of pen manure.

(2) The inorganic manure had a significant residual effect on the yield of first ratoon-canes, which was equal to the residual effect due to 30 tons of pen manure.

(3) The yield of second ratoon-canes on the inorganic plots was not significantly different from the mean yields on the remaining plots, which, on the average, were dressed with 15 tons of pen manure to the acre.

(4) The total yield for the crop series on the inorganic plots was equal to the total yield on the plots which received 20 tons of pen manure.

The financial gain resulting from the use of the inorganic manure is recorded in Table 3. It is far greater than the gain given by the optimum dose of pen manure.

It is now known that the composition of the inorganic manure used in Expt. I was far from ideal. The amount of phosphate it contained is considerably in excess of the requirements of the plant under the conditions obtaining in Trinidad, and it has since been shown that an excess of phosphate can depress the yield of sugar-cane under these conditions [6]. Further, the nitrogenous component of the inorganic manure was applied too late to be used to maximum advantage. These facts emphasize the merits of the inorganic manure in comparison with the fertilizing value of pen manure.

The results obtained in this experiment have been confirmed on other soil types in Trinidad. It has thus been possible to answer many of the arguments that have seriously affected the use of inorganic manures in the British West Indies [4].

(*b*) *Rate of diminution of increment in yield on the organic and inorganic plots.*—The data from Table 2 for average increments in yield are recorded in graphical form in Fig. 3. The curves exhibit a definite differ-

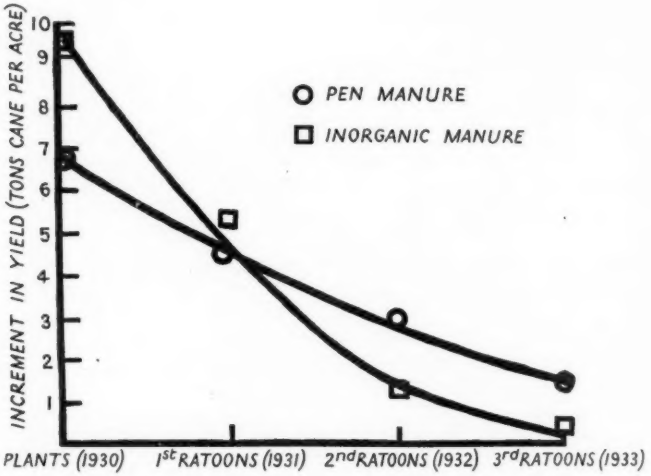


FIG. 3. Diminution of increment in yield with successive crops on plots treated with a single dressing of pen manure and of inorganic manure.

ence in slope. By the use of regression formulae [7] it may be shown that the average increment in yield on the pen-manured plots has gained on the increment in yield on the inorganic plots at the rate of 1·305 tons of cane a year. This annual gain is significant, and might be due to chance about once in 100 times. A gain of this nature may be caused by the fertilizer-constituents of pen manure becoming more available with time. It is also possible that the single application of pen manure may

have a small but definite effect on soil tilth. The trend of the curve for the inorganic manure suggests that its residual effect ceases with the crop of third ratoons. This conclusion is confirmed by the results of other experiments laid down in Trinidad. The residual effect of the organic manure appears also to vanish after the third-ratoon stage.

(*c*) *Pen manure as a fertilizer.*—The amounts of nitrogen, phosphate, and potash present in the inorganic manure, and the various dressings of pen manure, used in Expt. I, are set out in Table 5.

TABLE 5. *Amounts of Total Nitrogen, Phosphate, and Potash present in Dressings of Inorganic Manure and Pen Manure*

*Expt. I*

| *Component* | *Pen manure* | | | *Inorganic manure* |
|---|---|---|---|---|
| | *10 tons* | *20 tons* | *30 tons* | |
| N (lb.) . . . | 99 | 197 | 296 | 90 |
| $P_2O_5$ (lb.) . . | 45 | 90 | 134 | 375 |
| $K_2O$ (lb.) . . | 141 | 282 | 423 | 60 |

The dressing of 20 tons of pen manure contained more than twice as much nitrogen, and more than five times as much potash, as the inorganic manure. It can be stated that nitrogen and potash are the two elements primarily needed in the manurial treatment of sugar-cane under Trinidad conditions.

*Value of nitrogen in pen manure.*—By means of a series of field-experiments it has been shown that the raw clay soils on which Expt. II was laid down are definitely deficient in available nitrogen, and that on these soils sugar-cane responds generously to treatment with sulphate of ammonia [8]. Experience has shown that ample potash and phosphate were available in the soil of the experimental area for the four successive crops of plant- and ratoon-canes.

In this experiment the yield of plant-canes on the inorganic plots was equal to that on the plots which received a dressing of 30 tons of pen manure to the acre (Table 2). As far as *immediately available* nitrogen is concerned, it can therefore be concluded that the 300 lb. of total nitrogen in the 30 tons of pen manure were equivalent, from the standpoint of increment in yield, to the 90 lb. of nitrogen present as sulphate of ammonia in the inorganic manure. In this particular case, therefore, it appears that the nitrogen of pen manure is only 0·3 times as valuable as the inorganic nitrogen from the standpoint of immediate availability.

On the other hand, the total yield for the complete series of four crops on the inorganic plots was equal to that on the plots dressed with 20 tons of pen manure to the acre. When full account is taken of the residual effect of the pen manure, the nitrogen it contains becomes 0·45 times as valuable as an equivalent quantity of inorganic nitrogen, in this particular case.

It is not yet possible to make a similar comparison of the relative

value of potash and phosphate in inorganic and organic manures with any degree of accuracy.

(*d*) *Pen manure in relation to soil moisture.*—Pen manure is believed to facilitate the growth of sugar-cane by increasing the capacity of the soil to retain moisture in dry weather. An experiment laid down on a porous, volcanic soil, in the island of St. Kitts, B.W.I., is of interest in this respect (Table 6).

TABLE 6. *Effect of Pen Manure and Fish Manure on Yield of Cane on Light, Porous Soils*

(R. E. Kelsick [9])
Cane variety: B.H. 10/12
Lay-out: Two Latin squares

| *Treatment as plant-canes per acre* | *Plant-canes* | | *First ratoons* | | *Total* | |
|---|---|---|---|---|---|---|
| | *Yield per acre* | *Gain per acre* | *Yield per acre* | *Gain per acre* | *Yield per acre* | *Gain per acre* |
| None . . . . | 27·5 | .. | 27·6 | .. | 55·1 | .. |
| 25 tons pen manure . | 29·0 | 1·5 | 36·8 | 9·2 | 65·8 | 10·7 |
| 600 lb. fish manure . | 30·3 | 2·8 | 29·2 | 1·6 | 59·5 | 4·4 |

During the life of the plant-canes the weather was exceptionally dry. The increment in yield of plant-canes, due to treatment with pen manure, was only 1·5 tons, and definitely not significant. Under dry conditions the dressing of 25 tons of pen manure was no more effective than 0·27 tons of fish manure. During the life of the first ratoon-canes the rainfall was normal, and the residual effect of the pen manure on the yield of the ratoons was equal to 9·2 tons of cane. This increment might be due to chance less than once in 100 times. It appears that pen manure can give satisfactory results only when there is ample rainfall.

Similar results have been obtained in Trinidad in an experiment laid down on a soil containing 22 per cent. of clay. In this experiment certain plots received 20 tons of pen manure of good quality. During the wet weather, which preceded a dry spell, the plants on the pen-manured plots made much more rapid growth than those on the unmanured plots. In the ensuing drought, however, a greater number of plants died on the former plots than on the latter, thus reducing the gain in yield due to pen-manuring to the low value of 2·3 tons of cane. Any increase in the moisture-content of the soil caused by treatment with pen manure was inadequate to maintain at its original value the early lead gained by the manured plants.

## IV. *Pen Manure plus Inorganic Manures in Relation to Yield*

As long as live stock are extensively employed for working purposes on sugar-plantations, supplies of pen manure will be available and will be used in the field. As it seemed possible that artificial manures could be employed with advantage to supplement pen manure, experiments were laid down critically to explore the various possibilities.

(*a*) *An interaction of pen manure with sulphate of ammonia.*—Data are

recorded in Table 7 for three experiments in which are compared the increments in yield of plant-canes resulting from dressings of pen manure and sulphate of ammonia, when applied separately and in combination.

TABLE 7. *Effect of Pen Manure and Sulphate of Ammonia on Yield of Plant-canes*

P.M. = Pen manure
S/A = Sulphate of ammonia
Lay-out: 8×8 Latin squares

*Yield of cane (tons per acre)*

| *Experiment:* | V | | VI | | VII | |
|---|---|---|---|---|---|---|
| *Soil type:* | *Calcareous marl* | | *Acidic, raw clay* | | *Calcareous marl* | |
| *Cane variety:* | *B.H. 10/12* | | *Uba* | | *B.H. 10/12* | |
| *Treatment* | *Yield* | *Gain* | *Yield* | *Gain* | *Yield* | *Gain* |
| None | 43·05 | .. | 31·93 | .. | 26·66 | .. |
| P.M. | 47·74 | 4·69 | 36·97 | 5·04 | 30·64 | 3·98 |
| S/A | 52·88 | 9·83 | 45·16 | 13·23 | 34·10 | 7·44 |
| P.M.×S/A | 52·04 | 8·99 | 45·00 | 13·07 | 38·61 | 11·95 |

On the calcareous soils the dressing of pen manure was 15 tons to the acre; on the raw clay soil 20 tons was used. The dressing of sulphate of ammonia in the presence of pen manure was 2 cwt. per acre; in the absence of pen manure 3 cwt. were applied.

In Expts. V and VI the pen manure gave an average increase in yield of 4·86 tons of cane to the acre. Sulphate of ammonia gave a significantly larger average increment of 11·83 tons. The difference of 6·67 tons in favour of so small an application of sulphate of ammonia leaves no doubt that the amount of readily available nitrogen in 15–20 tons of pen manure is inadequate for maximum yield.

In these two experiments pen manure and sulphate of ammonia in combination gave an average increment in yield of 11·03 tons, a figure practically identical with that for sulphate of ammonia alone. It seems, therefore, that sulphate of ammonia can mask completely the increment in yield due to pen manure on both a calcareous soil type and an acidic, heavy, raw clay. It can be shown that the interaction of pen manure with sulphate of ammonia might be due to chance less than once in 20 times on the calcareous soil. On the raw clay the interaction cannot be established as significant. On both soil types the masking effect can be explained on the assumption that the value of the pen manure lies in the nitrogen rather than in the humus it supplies to the soil. It has been shown that neither soil type responds significantly to treatment with potash or phosphate.

In Expt. VII the increment in yield due to treatment with pen manure is approximately the same as in Expts. V and VI, but the increment due to sulphate of ammonia is only 7·44 tons. Further, in Expt. VII, the gain due to pen manure and sulphate of ammonia, when applied together, is roughly equal to the sum of the gains when each manure is applied independently. Expts. V and VII were laid down at the same time and on the same soil type. In each case the form of the experiment

was an 8×8 Latin square. The difference in the type of result obtained shows that further research is needed if maximum use is to be made of pen manure and sulphate of ammonia in combination.

Saint [5], in Barbados, has shown that increased yields of plant-canes result when sulphate of ammonia is applied in addition to pen manure on soils known to be deficient in nitrogen.

(*b*) *Pen manure and inorganic potash.*—The effect on yield of cane of applications of potash in the presence of basal dressings of pen manure and sulphate of ammonia has been measured [10]. The experiments were laid down on areas of an exhausted soil known to be deficient in exchangeable potash. Their primary aim was to determine whether the amount of potash present in pen manure is adequate for the needs of the plant on such soils. The data obtained are summarized in Table 8.

TABLE 8. *Effect of Potash on Yield of Plant-canes in presence of Pen Manure and Sulphate of Ammonia*

*Yield of plant-canes (tons per acre)*

| *Expt.* | *Treatment with sulphate of potash* | | *Increment in yield* | *Exchangeable potash in soil (per cent.)* |
|---|---|---|---|---|
| | *2 cwt. per acre* | *None* | | |
| VIII | 41·90 | 36·87 | 5·03 | 0·022 |
| IX | 42·06 | 36·87 | 5·19 | 0·021 |
| X | 36·08 | 33·05 | 3·03 | 0·028 |
| Average | 40·01 | 35·60 | 4·41 | 0·024 |

The three experimental areas received a basal dressing to the acre of 14 tons of pen manure and 4 cwt. of sulphate of ammonia. The pen manure was of good quality, less than 8 tons being prepared by each head of cattle in a year (Pen A, Table 1).

The average increment in yield due to treatment with sulphate of potash in the three experiments is 4·41 tons of cane. The basal dressing of pen manure contained about 200 lb. of $K_2O$. The soils of the experimental areas had previously been dressed with approximately 15 tons of pen manure to the acre at each replanting, i.e. once in every four years. It is evident that treatment with pen manure at these intervals did not maintain the fertility of the soil with respect to potash. It is further evident, for soils deficient in potash, that the maximum yield of plant-canes cannot be obtained with dressings of pen manure supplemented with sulphate of ammonia, and that it is necessary also to apply potash in inorganic form. The soils under experiment contain between 0·021 and 0·028 per cent. of exchangeable potash. The smallest increment in yield was obtained on the area containing most potash in this form (Table 8). As a rule, in Trinidad, sugar-cane responds to potash when only 0·02 per cent. is present in the soil. Response appears to be doubtful when the amount is as large as 0·04 per cent.

(*c*) *The interaction of pen manure with lime.*—Field-observations in Trinidad indicate that pen manure, when applied to soils which are naturally calcareous, or which have been thoroughly limed, decomposes with fair rapidity to form a sweet-smelling humus. On the other hand,

when applied to unflocculated lime-deficient soils, pen manure decomposes very slowly to form an evil-smelling product, which gives to soils of this nature a characteristic odour [8]. It is possible that two distinct types of decomposition occur. This suggests an interaction in the soil of lime with pen manure, which might be reflected in the yield of cane. There appear to be no references in the literature relating to a differential effect of pen manure in the presence and absence of lime. The data obtained in one of a series of experiments laid down in Trinidad to investigate the problem are recorded in Table 9.

TABLE 9. *Effect of Pen Manure on Yield of Plant-canes in presence of Increasing Dressings of Lime*

L.R. = Lime-requirement
Cane variety: B.H. 10/12
Soil type: Humus-deficient, raw clay soil
Lay-out: Three 8×8 Latin squares

*Yield of plant-canes (tons per acre)*

*Expt. XI*

| *Pen manure per acre* | *Treatment with ground limestone* | | | | *Average yield with lime* | *Average gain from lime* |
|---|---|---|---|---|---|---|
| | *None* | ½ *L.R.* | *L.R.* | 1½ *L.R.* | | |
| 20 tons . | 38·59 | 43·09 | 43·36 | 43·89 | 43·45 | 4·86 |
| None . . | 33·47 | 40·39 | 42·18 | 42·99 | 41·85 | 8·38 |
| Gain . . | 5·12 | 2·70 | 1·18 | 0·90 | 1·60 | 3·52 |

In this experiment the effect of the pen manure and of the lime on yield might be due to chance less than once in 100 times. Contrary to expectation, however, the gain in yield due to pen manure decreases continuously as the dose of lime increases. As there were 24 replicates of each individual treatment in the experiment it is possible to establish the significance of the interaction between lime and pen manure, which might be due to chance rather less than once in 20 times.

In every experiment of this kind laid down in Trinidad, the sum of the gains in yield on plots receiving pen manure without lime, and lime without pen manure, has invariably been larger than the gain on the plots which received both of these manures. No instance has yet been recorded in which the yield on the latter plots either equals or exceeds the sum of the increments on the former plots.

As far as it can be determined at present, this interaction of lime with pen manure is related to the content of exchangeable potash of the soil, and may be explained by assuming that increasing doses of lime render increasing amounts of potash available to the plant through base-exchange with the soil. Any effect on yield of the potash in the pen manure would be partly negatived by the potash thus released. In these circumstances the interaction of lime with pen manure would tend to be most evident when the soil contains moderate, but somewhat inadequate, quantities of this exchangeable base. In Expt. XI (Table 9) the average amount of potash present in this form in the soil of the unmanured

plots was 0·031 per cent. This amount lies between 0·02 per cent., which is known to be insufficient for the needs of the plant, and 0·04 per cent., which appears to be ample.

An experiment, identical in kind with Expt. XI, but laid down on a soil which contained 0·005 per cent. of exchangeable potash and which has been shown significantly to respond to dressings of potash, gave the following results:

TABLE 10. *Effect of Pen Manure on Yield of Plant-canes in presence of Increasing Dressings of Lime. Potash-deficient Soil*

Cane variety: B. 156

*Yield of cane (tons per acre)*

*Expt. XII*

| *Dressing of limestone* | *None* | *8 tons* | *16 tons* | *24 tons* | *Average for limed plots* |
|---|---|---|---|---|---|
| Gain due to 20 tons pen manure | 7·16 | 6·66 | 5·15 | 5·60 | 5·80 |

The average depression of the increment in yield due to liming in the presence of pen manure was only 1·36 tons of cane in Expt. XII. On this potash-deficient area the interaction of lime with pen manure is definitely not significant.

The data recorded in Tables 9 and 10 tend further to bring into prominence the particular value of pen manure as a source of plant nutrients.

(*d*) *Pen manure plus sulphate of ammonia versus a complete inorganic manure.*—The general trend of the accumulated experimental data led to the conclusion that artificial manures were worthy of an extended trial on a large scale under typical plantation conditions. Twelve fields were therefore selected on different sections of one plantation [11]. To one-half of each field a complete inorganic manure was applied, and the other half received a dressing of pen manure supplemented with sulphate of ammonia. The experiment covered 100 acres in all. The twelve fields were harvested at intervals spread over a period of three months. The yield and other data obtained for the plant-cane crop are recorded in Table 11.

On the average the complete inorganic manure gave slightly larger increments in yield of cane and of sugar than the dressing of pen manure and sulphate of ammonia. Analyses of juice showed that there was nothing to choose between the quality of the crop on the two plots. The cost per ton of cane on the former plots was only four-fifths of that on the latter plots. Further, 3·8 units of labour were required per ton of cane on the inorganic areas, whereas 4·5 units were needed on the pen-manured areas.

In view of the objections which have been raised to the use of inorganic manures on very heavy soils [4], it is worthy of note that the soils of seven of the twelve fields contained over 50 per cent. of clay. In four of the fields less than 25 per cent. of clay was present.

TABLE 11. *Pen Manure plus Sulphate of Ammonia versus Complete Inorganic Manure*

Treatments: I. 20 tons pen manure plus 4 cwt. S/A
II. 6 cwt. S/A plus 2 cwt. sulphate of potash plus 1 cwt. superphosphate

*Expt. XIII*

| *Field No.* | *Clay in soil per cent.* | *Tons cane per acre* | | *Tons sugar per acre* | |
|---|---|---|---|---|---|
| | | *Tr. I* | *Tr. II* | *Tr. I* | *Tr. II* |
| 1 | 63 | 36·36 | 48·25 | 3·21 | 4·29 |
| 2 | 62 | 55·09 | 49·91 | 4·95 | 4·24 |
| 3 | 63 | 45·94 | 61·77 | 4·24 | 5·39 |
| 4 | 18 | 39·95 | 40·41 | 4·54 | 4·71 |
| 5 | 53 | 40·12 | 41·24 | 4·62 | 4·74 |
| 6 | 57 | 36·27 | 45·07 | 3·73 | 4·86 |
| 7 | 57 | 46·25 | 46·69 | 4·78 | 4·55 |
| 8 | 51 | 56·23 | 57·77 | 5·74 | 5·80 |
| 9 | 34 | 44·04 | 50·57 | 4·44 | 4·98 |
| 10 | 24 | 52·70 | 53·29 | 6·75 | 6·89 |
| 11 | 16 | 33·25 | 32·82 | 3·99 | 3·94 |
| 12 | 22 | 41·75 | 45·16 | 4·94 | 5·47 |
| Average | 43 | 44·00 | 47·75 | 4·66 | 4·98 |

## V. *Pen Manure versus other Organic Manures*

(*a*) *Pen manure versus sheep manure.*—To assist in gauging the value of pen manure a dressing of sheep manure was included in one of the experiments with pen manure. The sheep manure contained 1·24 per cent. nitrogen, 0·54 per cent. phosphate (as $P_2O_5$) and 2·03 per cent. potash (as $K_2O$). The results of the comparison are recorded in Table 12. All the plots were given a basal dressing of 2 cwt. of sulphate of ammonia to the acre. The pen manure used was of average quality.

TABLE 12. *Relative Value of Sheep Manure and Pen Manure. Plant-canes*

Cane variety: B.H. 10/12
Lay-out: 7 randomized blocks

*Expt. XIV*

| *Treatment per acre* | *20 tons pen manure* | *2 tons sheep manure* |
|---|---|---|
| Yield of cane per acre | 36·19 tons | 38·64 tons |

The somewhat larger yield on the plots receiving sheep manure was statistically not significant. It appears that the effect of 2 tons of sheep manure on yield is roughly equivalent to that of 20 tons of pen manure; and calculation shows that the value of the nitrogen in pen manure is about 0·3 times that of the nitrogen in sheep manure.

(*b*) *Pen manure versus fish manure.*—Data comparing the effect of pen manure and fish manure on the yield of cane are recorded in Table 6. A dressing of 25 tons of pen manure to the acre gave a total increment in yield of 10·7 tons of plant- and first ratoon-canes; 600 lb.

of fish manure gave a corresponding gain of 4·4 tons. In this experiment, therefore, 25 tons of pen manure were equivalent to 0·7 tons of fish manure, from the standpoint of the total increment in yield.

*Summary*

I. The preparation and composition of plantation pen manure are briefly described.

II. *Effect of pen manure on yield.* It is shown that:

(i) The effect of a single dressing can persist over four crops.

(ii) The total residual effect on the ratoon-canes was approximately equal to the immediate effect on the plant-canes.

(iii) Although larger dressings can further increase yield, about 15 tons to the acre gave maximum financial gain.

(iv) Hardy canes appear to respond better to pen manure than noble canes.

III. *Pen manure versus inorganic manure.* Results obtained demonstrate that:

(i) Many of the objections that have seriously affected the use of inorganic manures in the West Indies are invalid.

(ii) Inorganic manure also has a definite residual effect on yield.

(iii) The rate of diminution of the residual increment in yield is greater with inorganic than pen manure.

(iv) The yield-value of nitrogen in pen manure is definitely smaller than the nitrogen in sulphate of ammonia.

IV. *Pen manure plus inorganic manure.* It is shown that:

(i) In certain circumstances sulphate of ammonia can completely mask the increment in yield due to pen manure.

(ii) A significant interaction can occur between pen manure and lime.

(iii) Pen manure is inadequate as a source of potash.

The general trend of the results obtained emphasizes the fertilizer value rather than any other attributes of pen manure.

V. *Sheep manure and fish manure* have been compared with pen manure.

REFERENCES

1. P. E. Turner, Studies on Sugar-cane and Sugar-cane Soils. Pt. I. Empire J. Expt. Agric., 1934, **2**, 78–92.
2. F. Hardy, Mauritian Pen Manure. Tropical Agriculture, 1924, **1**, 116.
3. Noel Deerr, Cane Sugar. London: Norman Rodger, 1921, p. 98.
4. P. E. Turner and J. A. Potter, Manurial Experiments with Sugar-cane, IV and VI. Tropical Agriculture, 1932, **9**, 44; 1933, **10**, 60.
5. S. J. Saint, Discussion of Results of Manurial Trials on Sugar-cane, 1928–32. Barbados Agric. J., 1932, **1**, p. 1.
6. P. E. Turner, Proc. Trinidad Sugar-cane Invest. Comm., 1932, **4**, pt. i, p. 31; pt. ii, p. 132.
7. R. A. Fisher, Statistical Methods for Research Workers, p. 118.
8. P. E. Turner, Some Manurial and Cultivation Experiments in Trinidad (1927–32). Proc. Agric. Soc. Trinidad and Tobago, 1933, **33**, 349.
9. R. E. Kelsick, Report on the Agricultural Dept. St. Kitts-Nevis, 1932, p. 9.
10. P. E. Turner, Tropical Agriculture, 1932, **9**, 206.
11. P. E. Turner, Proc. Trinidad Sugar-cane Invest. Comm., 1933, **4**, 78, 183.

(*Received February 20, 1934*)

# THE QUALITY OF WHEAT AS INFLUENCED BY ENVIRONMENT

FRANK T. SHUTT
(*Dominion Chemist and Assistant Director, Experimental Farms, Canada*)
and
S. N. HAMILTON (*Chemist*)

THE purpose of this paper is to present as concisely as possible, practically in the form of a summary, the results of an investigation inaugurated in 1905 to ascertain the influence of seasonal—and incidentally of soil—conditions on the protein-content of wheat. This is a question not merely of scientific interest but one of very considerable commercial importance, since protein is the outstanding constituent used in the evaluation of wheat by the flour-milling and baking industries.

*Quality in wheat.*—The main factors fixing the value of a wheat for milling purposes are the *amount* and *character* of its protein (commonly known as gluten, for this cereal); these, therefore, for practical purposes, constitute and determine its quality. The character of gluten—a complex problem—appears to be essentially an inherited factor, whereas the amount or percentage present may be markedly influenced by environment.

*Environment.*—The term environment used in its widest sense would include a number of factors, but those of first and paramount importance, as influencing the composition of the grain and more particularly its protein-content, are the climatic or seasonal conditions under which the grain is grown. It might be thought that richness of the soil, especially in nitrogen, would be a determinative factor of importance, but such, save in extreme instances and under abnormal conditions, does not appear to be the case. Many comparatively light sandy loams of moderate nitrogen-content in the western prairie provinces are producing wheat of protein-content equal to that from heavy loams exceedingly rich in nitrogen.

Climatic or seasonal conditions may and do affect, shorten or lengthen, the period of growth. It would appear that the period of time which elapses between the formation and the ripening of the kernel practically controls the gluten-content of wheat: the shorter the period the higher the percentage of gluten. High temperatures and absence of excessive moisture during the latter stage of the kernel's development shorten this period, hasten ripening, and result in a high-protein wheat; on the other hand, cool and wet weather in the latter part of the season prolongs the development period, retards ripening, and results in a more or less starchy grain. In this inquiry, therefore, it will be understood that seasonal conditions, rainfall and temperature, constitute environment. It must be pointed out, however, that the character of the soil, more particularly in respect to its absorptive capacity for moisture, is necessarily a factor closely associated with precipitation in hastening or retarding the ripening of the crop.

*Heredity.*—It has been found that heredity, although extremely influential as a factor in affecting the character of the protein (gluten), is certainly not the dominant factor in determining the percentage of this constituent stored up in the grain. The wheat-breeder has recognized and taken advantage of the fact that the period of growth, i.e. the length of time between germination and the harvesting of the fully ripened grain, is an inherited characteristic. This phase of research has been of almost immeasurable value to the prairie provinces. Nevertheless, the same variety will have its protein-content markedly affected by the environmental conditions under which it is grown and more particularly by those prevailing during the latter weeks of the season.[1]

### *History and Data of the Investigation, 1905–32*

The investigation here discussed dates back to 1905, when the writers' attention was first directed to the fact that hard, semi-translucent, high-gluten wheat when grown on newly cleared scrub-land in northern Manitoba produced grain which was more or less starchy and soft (commonly known as 'piebald'), with a decidedly lower protein-content than the hard parent-wheat. This change, from the commercial point of view, marks a deterioration in quality.

As an initial step towards ascertaining the cause or causes of this softening of wheat, an area was selected in 1905 on recently cleared and broken scrub-land at Valley River, Dauphin Lake district, northern Manitoba. This area was sown with high-quality hard wheat (Red Fife) grown in southern Manitoba. The harvested grain was decidedly 'soft', with many opaque, starchy grains, thus confirming the statement that the quality deteriorates when wheat is grown on newly cleared scrub-land in northern Manitoba. The parent wheat contained 2·17 and the harvested wheat 1·94 per cent. nitrogen.

In the season of 1906 the plan of work was as follows. Two wheats were used: one, grown at Valley River in 1905, that produced on 'breaking' a piebald grain with a nitrogen-content of 1·94 per cent.; the other, an exceedingly good sample of hard vitreous wheat, grown at Hartney, southern Manitoba, had a nitrogen-content of 2·71 per cent.

Each of these was grown at Valley River on 'breaking' and cultivated land; the former had been cleared and ploughed the previous season (1905), the latter had been 'broken' nine years previously, and had borne seven successive crops of grain.

This procedure was determined partly to obtain, if possible, chemical data which would support the statement that the quality of wheat in this district showed a distinct improvement with cultivation of the land, and, a point of equal importance, partly to learn if the soil of the newly broken land had not a higher moisture-content throughout the season, more especially during its later weeks, this higher moisture-content in the ripening period being related to the production of a starchy wheat of lower protein-content.

[1] In order that the data from other countries investigating this problem may be strictly comparable, the figures in the tables are for nitrogen and not protein—thus precluding the possibility of different conversion factors being used.

To interpret more fully the analytical data of the harvested wheats, complete analyses were made of the two soils, and their moisture-contents were determined at seven intervals between May 1 and September 1. The data were as follows:

TABLE 1. *Water in 'Breaking' and 'Cultivated' Soils at Valley River, Manitoba, May–August, 1906*

| | *May 5* % | *May 15* % | *May 29* % | *June 22* % | *July 13* % | *Aug. 2* % | *Aug. 24* % |
|---|---|---|---|---|---|---|---|
| Breaking | 32·96 | 36·49 | 33·45 | 30·49 | 35·23 | 30·37 | 32·84 |
| Cultivated | 22·45 | 23·39 | 23·39 | 21·70 | 21·24 | 13·24 | 18·28 |

A truly remarkable difference in the moisture-content of these two soils is to be noticed throughout the growing season, the 'breaking' soils always containing from 9 to 14 per cent. more water than those of the 'cultivated' area.

A composite sample of the soil of each plot was made by thoroughly mixing the seven individual samples. The air-dried and prepared samples were analysed and the following results obtained:

TABLE 2. *Analysis of (Air-dried) Soils*

| | *Breaking* % | *Cultivated* % |
|---|---|---|
| Moisture | 2·98 | 2·06 |
| Organic and volatile matter | 20·90 | 12·84 |
| Insoluble residue (clay, sand, &c.) | 51·74 | 65·07 |
| Oxide of iron and alumina | 5·50 | 10·52 |
| Lime | 10·50 | 3·47 |
| Magnesia | 2·44 | 1·63 |
| Potash | 0·14 | 0·19 |
| Phosphoric acid | 0·15 | 0·13 |
| Soluble silica | 0·02 | 0·02 |
| Carbon dioxide, &c. (undetermined) | 5·63 | 4·07 |
| | 100·00 | 100·00 |
| Nitrogen in organic matter | 0·642 | 0·371 |
| Available constituents: | | |
| Phosphoric acid | 0·0067 | 0·0067 |
| Potash | 0·0166 | 0·0069 |
| Lime | 1·306 | 0·93 |

The characteristic feature of these soils is their richness in vegetable matter and their high nitrogen-content, and it is especially noteworthy that the breaking soil is much richer in these constituents than the cultivated soil. The higher humus-content naturally gives the breaking soil a greater absorptive and retentive power for water and, taken in conjunction with the thorough cultivation which this soil had received in the previous season, readily accounts for its higher moisture-content. This destruction of organic matter and dissipation of nitrogen resulting

from cultivation has been previously demonstrated by investigations on rich prairie soils.[1]

Little need be said here regarding the rest of the analytical data. Both soils are apparently well supplied with the mineral elements of plant-food, that which is latent or in reserve as well as that which is more or less immediately available, though the percentages of phosphoric acid and potash are not quite equal to those in the stronger, i.e. more clayey, soils of the North-West. Important, however, is the good proportion of lime, more particularly in the breaking soil, an excellent indication of the fertility of these soils when taken in conjunction with the rest of the data. If we assume that originally the whole area was covered with similar soil, we have in these results an excellent illustration of the 'working down' of lime under cultivation.

TABLE 3. *Moisture and Organic Matter in Breaking and Cultivated Soils: Nitrogen in Wheats*

| | *Soil* | | *Nitrogen in wheat* | |
|---|---|---|---|---|
| | *Average moisture for 7 dates during growing season May 1 to Sept. 1* | *Organic matter (d.m. basis)* | *Parent-seed from breaking, 1905, nitrogen 1·94%* | *Parent-seed from Hartney, nitrogen 2·71%* |
| | % | % | % | % |
| Breaking . | 33·12 | 21·54 | 1·95 | 2·37 |
| Cultivated . | 20·53 | 13·11 | 2·64 | 2·30 |

## *Discussion of Results*

*Wheat on breaking soil.*—On the breaking soil, with its higher moisture-content throughout the season, the wheat harvested from both parents was decidedly soft, piebald, and of low protein-content. The grain from the seed produced the year before on breaking contained much more starch and was very similar in appearance and protein-content to its parent. The wheat from the Hartney seed (hard, with a high protein-content) is 0·34 per cent. lower in nitrogen than its parent—a marked deterioration due, presumably, to environmental (soil and moisture) conditions.

*Wheat on cultivated soil.*—The nitrogen-content of the harvested grain from the cultivated soil is 0·70 per cent. higher than that of the parent and of its progeny grown on the breaking soil in 1905 and 1906, thus supporting the view that in this district the quality of the wheat improves with cultivation of the soil.

Considering the results from the Hartney parent-seed (hard, high-protein wheat), it will be observed that there has been a distinct lowering of nitrogen in the grain from both soils. This decrease is slightly less in the wheat from the breaking (moister) soil than in that from the cultivated area; it is not in strict accord with the view that increased moisture-

[1] *Western Prairie Soils; their nature and composition.* Bulletin No. 22, New Series, Dept. of Agriculture, Dominion of Canada.

content of the soil tends to lower the protein-content, and no very satisfactory explanation for this apparent exception can be offered. Both results, however, show the trend towards deterioration of the wheat on the breaking (moister) soil.

The work was continued in 1907 at Valley River, Manitoba, and a similar set of experiments was instituted at Tisdale, Saskatchewan, but owing to unfavourable seasonal conditions—low summer temperatures accompanied by unusually heavy precipitation with severe frosts in early autumn—the grain at neither point advanced past the early dough stage.

### *The Influence of Irrigation*

*1908.*—If the conclusions reached from the foregoing work are in the main correct, viz. that excessive moisture, more particularly when associated with comparatively low temperatures during the latter part of the season, is the chief factor conducive to a soft, low-protein wheat, then it might be conjectured that wheat grown under irrigation (water being supplied throughout the season) would contain a lower percentage of protein than the same wheat under 'dry' land conditions, with a sparse precipitation.

In order to secure data which might support this hypothesis, irrigated and non-irrigated (dry land) areas were sown in the season of 1908 at the Experimental Station, Lethbridge, southern Alberta, with Red Fife and Kharkov wheats. This district is usually one of sparse precipitation and consequently one in which the methods of so-called 'dry farming' must be practised in places where there is no provision for irrigation. As a rule, irrigation is necessary for maximum yields.

The season during the earlier months was unusually wet, and consequently not favourable to the experiment in hand. Only one irrigation was found necessary, owing to the ample rainfall referred to, and this was not made until July 15, immediately following the second collection of soil samples for determining moisture-content.

The percentages of moisture in the soil of these areas, as determined at intervals throughout the season, in samples taken to a depth of 14 inches, were as follows:

TABLE 4. *Moisture in Irrigated and Non-irrigated Soils, Lethbridge, Alta., 1908*

| | *Irrigated* % | *Non-irrigated* % |
|---|---|---|
| May 14 . . . . | 16·56 | 15·61 |
| July 15 . . . . | 8·78 | 8·11 |
| August 17 . . . . | 10·37 | 6·38 |

Until July 15, therefore, the moisture-content was almost the same for both the areas under examination, but subsequent to that date, i.e. during the ripening period of the wheat, that of the irrigated was considerably higher than that of the non-irrigated area.

*Analysis of Wheats*

| | *Nitrogen* % |
|---|---|
| Red Fife, parent-seed, grown at Brandon, Man. | 2·92 |
| „ product on irrigated land | 2·46 |
| „ „ 'dry' land | 2·93 |
| Kharkov, parent seed | — |
| „ product on irrigated land | 2·19 |
| „ „ 'dry' land | 2·33 |

In the case of Red Fife a difference of 0·47 per cent. and in that of Kharkov of 0·14 per cent. of nitrogen, is to be observed, the richer wheat in both instances being from the dry land plots—the soil that had more rapidly dried out during the ripening period. These results are as was conjectured, and are in agreement with those obtained in northern Manitoba in 1905 and 1906.

*1909.*—These experiments were continued in 1909. The moisture-content of the two areas, irrigated and non-irrigated, was determined from the middle of July to the end of August, the weeks during which the grain was completing its development.

TABLE 5. *Moisture in Irrigated and Non-irrigated Soils, 1909*

| *Date of collection (samples collected to a depth of 14 inches)* | *Irrigated (a)* | *Non-irrigated* |
|---|---|---|
| | % | % |
| July 16 | 9·62 | 8·50 |
| August 1 | 8·19 | 6·20 |
| „ 25 | 8·16 | 5·99 |

(*a*) One irrigation only was made on July 10.

It is significant that during the above-mentioned period the irrigated land lost 1·46 per cent. moisture and the non-irrigated lost 2·51 per cent.; also that at the first collection the non-irrigated land was approximately only 1 per cent. drier than the irrigated soil. These differences may appear small when expressed in percentages, but when it is remembered that the weight of an acre of soil to a depth of 14 inches is of the order of 3,500,000 lb., it follows that the apparently insignificant difference of 1 per cent. becomes of moment, as it is equivalent to about 17·5 tons more water per acre available for the crop's need.

The nitrogen-content of the parent-wheat (Red Fife) and of its products on the irrigated and non-irrigated (dry land) plots may be given as follows:

TABLE 6. *Nitrogen-content of Wheat on Irrigated and Non-irrigated Soils, Lethbridge, Alta.*

| | *Nitrogen* % |
|---|---|
| Parent-seed, grown on non-irrigated dry land at Lethbridge, 1908 | 2·72 |
| Product on irrigated land | 2·29 |
| „ non-irrigated land | 3·15 |

The difference in nitrogen-content here observed between the wheats grown on irrigated and non-irrigated soils, 0·71 per cent., is phenomenally large and, being in the same directions as previous results, assuredly supports in a very emphatic manner the contention that the amount of available moisture during the filling out of the grain affects its protein-content.

It is interesting to note that the progeny of the parent-seed grown in 1908 showed, on non-irrigated land, an improvement in nitrogen-content in the drier season (1909) of 0·43 per cent., and a deterioration, if such it may be called, of 0·43 per cent. when grown on irrigated soil.

*1910.*—The further prosecution of this inquiry at the Experimental Station, Lethbridge, during the season of 1910 comprised trials with wheat under irrigation and dry-farming conditions. In addition to the analysis of the parent-seed and of the crop, determinations of the moisture-content of the several plots were made throughout the season.

The moisture-content of the irrigated and non-irrigated areas, as determined several times during the season to a depth of 14 inches, may be stated as follows:

TABLE 7. *Moisture-content of Wheat Plots*

| | *Irrigated* % | *Non-irrigated* % |
|---|---|---|
| May 25 | 11·57 | 11·75 |
| June 21 | 6·73 | 7·19 |
| July 4 | 13·62 | 7·14 |
| „ 10 | 8·87 | 6·61 |
| „ 18 | 13·20 | 6·05 |
| August 1 | 8·19 | 5·22 |

The plots used in this investigation, on the irrigated and non-irrigated areas alike, had been summer-fallowed in 1909, so that but slight differences, if any, might be expected in their moisture-content at the opening of the season, 1910. That such is the case will be seen from the data for May 25. A month later (June 21), the moisture-content on both areas, though considerably reduced, was still practically identical. Since the seed was sown on April 1, it is evident that the environment, in so far as soil moisture is concerned, had been the same for the wheat on both areas during the major period of its growth. Further, this period was an exceedingly dry one, certainly the driest since reliable meteorological observations have been recorded at Lethbridge.

Immediately after the collection of the second set of samples, the first irrigation was made (June 22), and the third series was not taken till a fortnight later (July 4), when the irrigated plots contained approximately twice the amount of moisture present in the non-irrigated area. The percentage of moisture in the latter was practically the same as on June 21. On July 10 the moisture was decidedly low on both areas, though there was a difference of 2 per cent. in favour of the irrigated land.

The second irrigation was on July 13, and the fifth collection of samples was made five days later on July 18. We find moisture conditions very

similar to those of July 4: a very low moisture-content in the soil of the non-irrigated area and approximately twice the amount in the irrigated soil. The sixth and last collection was on August 1, when the crop on both areas was harvested. Again, we find the soil very dry; in the non-irrigated land there was but 5·22 per cent., whilst in the irrigated area the soil contained only 8·19 per cent.

Our conclusions from these data are as follows: (1) that both plots started with practically the same moisture-content, a very fair but not excessive amount. (2) That the non-irrigated area dried out continuously until the grain was harvested. The lowering of the moisture-content was more rapid during the first examination period, May 25 to June 21, than during any subsequent period of the same duration. From this it may be inferred, judging from results on the irrigated area, that the low moisture-content at the latter date had obtained for some time previous to this second examination. (3) That on the irrigated area, until the first flooding (June 22), the soil was not more moist than that of the non-irrigated, indeed, it would seem to be somewhat the drier of the two; further, that the drying-out of the irrigated plots after each flooding was very rapid, from which it is clear that the crops upon them were, for the most part, in a fairly dry soil and only intermittently enjoyed an abundant supply of moisture.

Two samples of Red Fife wheat were used for sowing these areas; the one grown on non-irrigated land, the other on irrigated. Both of these parent-seeds had been obtained in this investigation at the Experimental Station, Lethbridge, Alta., the previous season, 1909.

The nitrogen-content and weight of 1,000 kernels of the wheats from the several plots are given in Table 8:

TABLE 8. *Wheat: 1,000-kernel weight and nitrogen-content from irrigated and non-irrigated land*

| | *Weight of 1,000 kernels gm.* | *Nitrogen %* |
|---|---|---|
| A. Parent-seed, grown on irrigated land, 1909 . | 36·6653 | 2·38 |
| Product on irrigated land . . . . | 30·8567 | 3·22 |
| ,, non-irrigated land . . . | 25·8823 | 3·28 |
| B. Parent-seed, grown on non-irrigated land, 1909 . | 31·2698 | 3·14 |
| Product on irrigated land . . . . | 30·2744 | 2·97 |
| ,, non-irrigated land . . . | 26·1502 | 3·34 |

Attention may first be directed to the great difference in nitrogen-content, 0·76 per cent. between the two parent-seeds of the crop of 1909; the higher—in accord with our previous work—being from the non-irrigated area.

In Expt. A the crops from both irrigated and non-irrigated areas are practically identical in protein-content and very much higher than the parent-seed which had been raised on irrigated land the previous season. That the wheat harvested from the non-irrigated area should be richer in protein than its parent was fully expected from our results of the past

five years, but that the crop from the irrigated area should be similarly high can only be explained on the ground that the moisture conditions of this plot during an important period in the life of the plant did not differ materially from those of the non-irrigated area. The data, indeed, seem to point to the conclusion that until the first irrigation, 83 days from seeding, the soil of the irrigated area was even drier than that of the non-irrigated.

In Expt. B wheat from non-irrigated land (1909) was employed, and as a consequence a high-protein seed was sown. Its product on non-irrigated land was still rich in protein, a result in accord with our conjecture that the season was one of unusual dryness. The crop from the irrigated land was found to be about 1 per cent. lower in protein than the parent-seed. This is certainly not a large difference, but it is one in the direction expected from previous results. That it is not larger may be accounted for by the facts alluded to in discussing Expt. A.

### *Extension of the Investigation*

The results of the work in northern Manitoba and southern Alberta had pointed to the conclusion that environmental conditions leading to a rapid development and maturation of the grain tends to produce a berry of high protein-content and excellent milling quality, and conversely, that conditions conducive to prolonging the vegetative processes favour the production of a starchy grain. These conclusions appeared to have great economic significance, looking to the future of the prairie provinces, and it was therefore thought well to pursue and extend the inquiry.

To obtain further data which might confirm or refute them, it was planned to grow wheat of the same stock on the branch-farms and stations of the Dominion Experimental Farm System, comparing the protein-content of the harvested grain with that of the parent-seed. It was further decided to make weekly observations respecting stage of growth, and to record as fully as might be practicable meteorological and allied data from the time of seeding to that of harvesting the crop. In this latter phase of the work the Director of the Dominion Meteorological Service has co-operated, and the questionnaire or 'observation sheet' used in recording the data was drawn up with his assistance. The scheme as a whole, comprising as it does the growing of wheat of the same stock right across Canada and at points with widely different seasonal conditions, should furnish material of the greatest value towards the solution of this important problem—the influence of environment on the protein-content of the grain.

In 1911 the parent- or stock-seed (Red Fife grown at Indian Head, Sask., 1910) was sown on plots at eleven of the farms and stations—every province being represented except New Brunswick. Unfortunately, the eleven samples of harvested wheat included five which bore indications of frost; three were quite green and shrivelled, and two evidently had been frozen while not yet fully ripe. The condition of these samples made conclusions from these data worthless. These disappointing results led us to decide that it would be desirable to substitute the

new wheat Marquis for the Red Fife previously used in the inquiry. Concerning this new variety the Dominion Cerealist wrote in November, 1912: 'The Marquis is now displacing all other varieties, including Red Fife, in the great wheat-growing provinces. It is about a week earlier in ripening than Red Fife, produces usually from 10 to 60 per cent. more crop [in Saskatchewan] and yields flour of the same character as Red Fife.' Marquis therefore is the variety used in this work from 1912 onwards. It was fortunate that the change was made at this time for Marquis has since become the dominant variety for the wheat-growing districts of the prairie provinces.

The farms and stations upon which plots were sown in 1912 were eleven in number, located as follows: Charlottetown, P.E.I., Nappan, N.S., Cap Rouge, Que., Ottawa, Ont., Brandon, Man., Indian Head, Rosthern and Scott, Sask., Lethbridge and Lacombe, Alta., and Agassiz, B.C. From time to time as other stations were established, they were added to the list; in 1932 the stations, in addition to those above enumerated, were located at Kentville, N.S., Fredericton, N.B., Ste Anne de la Pocatière, Que., Kapuskasing, Ont., Morden, Man., Swift Current, Sask., Fort Vermilion, Alta., Invermere and Summerland, B.C.

The seed sown at all the stations co-operating in this inquiry has been from the same stock, Marquis grown at Indian Head, Sask. It is therefore apparent that during the whole period of the investigation there has been no interfering factor in respect to variety, and that the differences in protein-content between the parent-seed and its product at the several stations must be attributed to environmental conditions.

The analytical work on the samples of 1912 to 1932, inclusive, has been completed. Appendix A presents the data for the weight of 1,000 kernels and nitrogen (dry-matter basis) for all the stations for the 21-year period. The data amassed are voluminous and require exhaustive study to bring out their full significance. However, a preliminary review has resulted in bringing to light certain interesting and important deductions which bear upon the relation of environment to protein-content.

Of the twenty-one maxima, six were from the crop of Invermere, B.C., under 'dry-farming' conditions, four from Scott, north-western Saskatchewan, two each from Agassiz, Lethbridge (dry land) and Swift Current, and one each from Ottawa, Rosthern, Lacombe, Fort Vermilion and Brandon. Of the twenty-one minima, twelve were from plots on stations in the maritime provinces (Charlottetown, Kentville, Nappan, Fredericton) three from Kapuskasing, Ontario, two from Cap Rouge, Que., two from irrigated lands at Invermere, B.C., and one each from Ottawa, Agassiz, and Fort Vermilion.

Since, as will be readily admitted, seasons may and will vary from year to year for any locality, it follows, if the theory that environmental conditions affect the protein-content is correct, that the *same* differences in this regard between the parent-seed and its product, will not persist at any one locality from year to year. The chemical data show this to be the case; variations of considerable magnitude from the parent-seed—both increase and decrease in protein—have occurred from season to season at nearly all the stations.

Comparing the nitrogen-content of the parent-seed with that of its product at the several stations, we note that a large variation is possible. This is shown in the following table.

TABLE 9. *Variation in Nitrogen-content of Marquis Wheats, from Coast to Coast, 1912–32*

| | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % | % |
| Parent-seed . | 2·57 | 3·03 | 2·20 | 2·39 | 2·71 | 2·43 | 2·85 | 2·58 | 2·89 | 2·82 | 2·72 |
| Maximum . . | 3·18 | 3·33 | 3·28 | 3·27 | 3·06 | 3·47 | 3·55 | 3·18 | 3·22 | 3·23 | 3·73 |
| Minimum . . | 2·19 | 2·15 | 2·13 | 2·04 | 1·88 | 2·36 | 1·77 | 1·93 | 1·87 | 2·14 | 2·27 |
| Variation from + | 0·61 | 0·30 | 1·08 | 0·88 | 0·35 | 1·04 | 0·70 | 0·60 | 0·33 | 0·41 | 1·02 |
| parent-seed — | 0·38 | 0·88 | 0·07 | 0·35 | 0·83 | 0·07 | 1·08 | 0·65 | 1·02 | 0·68 | 0·45 |

| | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % |
| Parent-seed . | 2·77 | 2·98 | 2·85 | 2·72 | 2·82 | 2·86 | 2·38 | 2·89 | 2·94 | 3·04 |
| Maximum . . | 3·16 | 3·17 | 3·47 | 3·22 | 3·13 | 3·36 | 3·86 | 3·31 | 3·24 | 3·38 |
| Minimum . . | 2·06 | 2·15 | 2·21 | 1·68 | 2·13 | 2·17 | 1·95 | 2·05 | 2·12 | 2·16 |
| Variation from + | 0·39 | 0·19 | 0·62 | 0·50 | 0·31 | 0·50 | 1·48 | 0·42 | 0·30 | 0·34 |
| parent-seed — | 0·71 | 0·83 | 0·64 | 0·04 | 0·69 | 0·69 | 0·43 | 0·84 | 0·82 | 0·88 |

From this record it will be seen that the nitrogen-content has been increased by environmental factors by 1·48 per cent. (1929) and reduced by 1·08 per cent. (1918).

Over a period of years, however, the usually prevailing seasonal conditions will be reflected in the average protein-content of the grain.

In Appendix B the average weight of 1,000 kernels and the average nitrogen-content for the 21-year period are presented, the stations being arranged geographically from the Atlantic to the Pacific.

In Appendix C the same data are given, the stations being ranked according to nitrogen-content. In this table the stations have been divided into two groups, viz. those where the average nitrogen-content is over 2·50 per cent., and those at which the average percentage of nitrogen is below 2·50 per cent.

The range in nitrogen for the first group is from 3·19 to 2·68 per cent. It includes the stations in Alberta and Saskatchewan where high summer temperatures and light rainfalls prevail in the later weeks of the season and also points in Manitoba, British Columbia, and Ontario, where similar, but not so marked, seasonal conditions prevail.

The wheat at the stations of the second group have an average nitrogen-content of from 2·48 to 2·21 per cent., and comprise mainly those in the maritime stations, but also two from Quebec and one from a point in northern Ontario where precipitations are heavier and maximum temperatures lower than at the stations comprising the first group.

*Influence of irrigation.*—The influence of irrigation is well marked; in every instance the irrigated wheat, as compared with that from dry land, is characterized by a lower nitrogen-content, a heavier kernel and a longer growing-period. Thus, considering averages, the irrigated wheat is 0·75 per cent. lower in nitrogen, 9 grammes heavier per 1,000 kernels, and has a growing-period longer by 12 days than the dry-land wheat.

Since among the environmental factors affecting these areas the only one markedly differing is soil-moisture, it is clear that the evidence of this experiment supports the contention that shortening the growing-period (hastening the ripening of the grain) increases the protein-content.

TABLE 10. *Influence of Irrigation on Marquis Wheat grown on Irrigated and Non-irrigated (Dry Land) Soils at Invermere (Windermere), B.C.*

Period of Growth: Weight of Kernels: Nitrogen (Dry-matter Basis)

| *Year* | *Growing-period* | | *Weight of 1,000 kernels* | | *Nitrogen (dry-matter basis)* | |
|---|---|---|---|---|---|---|
| | *Non-irrigated (dry land)* | *Irrigated* | *Non-irrigated (dry land)* | *Irrigated* | *Non-irrigated (dry land)* | *Irrigated* |
| | days | days | gm. | gm. | % | % |
| 1916 | .. | .. | 33·94 | 37·41 | 2·83 | 1·88 |
| 1917 | .. | .. | 22·57 | 24·57 | 3·47 | 2·42 |
| 1919 | .. | .. | 28·45 | 40·68 | 3·18 | 2·21 |
| 1920 | .. | .. | 21·10 | 34·25 | 3·22 | 2·01 |
| 1921 | 98 | 120 | 23·30 | 36·96 | 3·06 | 2·65 |
| 1922 | 103 | 117 | 26·33 | 37·69 | 2·75 | 2·44 |
| 1923 | 107 | 119 | 27·77 | 34·09 | 3·16 | 2·52 |
| 1926 | 100 | 119 | 21·99 | 35·15 | 3·41 | 2·44 |
| 1927 | 109 | 109 | 26·69 | 28·53 | 3·13 | 2·81 |
| 1928 | 110 | 110 | 26·43 | 27·03 | 3·89 | 2·74 |
| 1929 | 99 | 106 | 20·14 | 37·41 | 3·34 | 2·19 |
| 1931 | 109 | 122 | 26·47 | 38·70 | 3·24 | 2·93 |
| *Average* | 104 | 116 | 25·43 | 34·37 | 3·19 | 2·44 |

There is a relation between protein-content and weight of kernel when considering samples of the same variety which have normally ripened: the lighter the grain, within certain limits, the higher the percentage of protein. The relation is not a constant one; it undoubtedly varies with the seasonal conditions of the locality and necessarily from year to year, but it is usually evident under the conditions named above. Although weight of kernel cannot be used for predicting exactly the protein-content, it may serve as a guide to estimating, approximately, richness in protein, the samples being of the same variety.

*Influence of rainfall.*—Rainfall is the most important factor determining soil-moisture content and the supply of available plant-food. According to the present hypothesis it is the drying-out of the soil, due to scanty precipitation and high temperatures during the latter weeks of development, and ripening of the kernel which constitute the chief environmental factor conducive to high protein-content.

Limitation of space precludes the presentation and discussion of the data showing the correlation of rainfall and nitrogen at all the stations involved in this investigation. It has in consequence been decided to select four stations for detailed study: two in districts of scanty precipitation and high temperatures, and two in regions usually enjoying a heavier rainfall and lower temperatures during the latter weeks of the season. The two former are at Invermere (Upper Columbia Valley), B.C., and Scott, northern Saskatchewan, and the latter at Charlottetown, P.E. Island, and Kentville, N.S., in the maritime provinces.

The following table presents the data for the average maxima temperatures and precipitation for July and August and the average nitrogen-

content of the wheat (dry-matter basis) at the four above-mentioned stations over a period of twenty-one years, 1912–32.

TABLE 11. *Temperature, Rainfall, and Nitrogen-content of Wheat at Invermere, B.C., Scott, Sask., Charlottetown, P.E.I., Kentville, N.S. 1912–32*

| | *Temperature* | | *Rainfall* | | | | | | *Nitrogen* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *July* | | | *August* | | | | | |
| | *July. Average of maxima* | *August. Average of maxima* | *Maximum* | *Minimum* | *Average* | *Maximum* | *Minimum* | *Average* | *Maximum* | *Minimum* | *Average* |
| | ° F. | ° F. | in. | in. | in. | in. | in. | in. | % | % | % |
| Invermere, B.C. | 92 | 90 | 3·79 | 0·09 | 1·05 | 3·23 | 0·38 | 1·38 | 3·47 | 2·75 | 3·05 |
| Scott, Sask. | 93 | 91 | 6·16 | 0·67 | 2·49 | 3·87 | 0·35 | 1·53 | 3·55 | 2·73 | 3·06 |
| Charlottetown, P.E.I. | 84 | 82 | 6·83 | 1·00 | 3·22 | 6·97 | 1·37 | 3·21 | 2·83 | 1·82 | 2·30 |
| Kentville, N.S. | 85 | 86 | 5·63 | 0·99 | 3·07 | 9·39 | 0·86 | 3·09 | 3·10 | 1·68 | 2·36 |

It will be observed that these data fall into two groups, one consisting of the two western stations characterized by high ripening-temperatures, scanty rainfall, especially in August, and high-nitrogen wheat, the other —the two maritime stations—with lower temperatures, heavier rainfall, and grain of low nitrogen-content.

From the above data, averages (1) for the two western stations and (2) for the two maritime stations are presented in Table 12.

TABLE 12. *Average Temperature, Rainfall and Nitrogen-content for Western and Maritime Stations*

| *Station* | *Average data for ripening months (July–August)* | | *Nitrogen-content (dry-matter basis)* |
|---|---|---|---|
| | *Temperature (maxima)* | *Rainfall* | |
| | ° F. | in. | % |
| Western | 92 | 1·51 | 3·06 |
| Maritime | 84 | 3·15 | 2·33 |

Since the parent-seed wheat sown each season at all the Stations was of the same stock and consequently of the same composition, the evidence furnished by this investigation shows indisputably that environmental factors very largely determine the protein-content. From the above averages it will be seen that a difference of 0·73 per cent. of nitrogen has resulted solely from the influence of seasonal and soil conditions; heredity has played no part in the variation of the protein-content from that of the parent-seed.

The data amassed in this investigation covering a period from 1905 until the present time—28 years—and conducted at a considerable number of stations located at strategic points throughout the Dominion, very clearly prove that, in general, the excellent quality of the wheat of

the prairie provinces is very largely due to favourable seasonal conditions, which include high temperatures and absence of excessive moisture (resulting in the drying-out of the soil) during the latter stages of the development of the grain. For the production of high-quality wheat the economic value of these conditions—and they are those which usually obtain over the larger part of the wheat-belt of the great North-West—has not been sufficiently recognized. It is fully equal in importance to that of desirable inherited characteristics, e.g. quality of gluten and earliness in ripening, and an exceedingly fertile soil.

(*Received December 8, 1933*)

## APPENDIX A

## INFLUENCE OF ENVIRONMENT ON THE QUALITY OF WHEAT

*Marquis Wheat. Nitrogen (Dry-matter Basis): Weight of Kernels.*

*Experimental Farms and Stations, 1912–32*

| | *Parent-seed* | | *Charlottetown, P.E.I.* | | *Kentville, N.S.* | | *Nappan, N.S.* | | *Fredericton, N.B.* | | *Cap Rouge, P.Q.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* |
| | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % |
| 1912 | 37·40 | 2·57 | 31·15 | 2·19 | .. | .. | 31·42 | 2·33 | .. | .. | 31·96 | 2·63 |
| 13 | 38·18 | 3·03 | 36·76 | 2·15 | .. | .. | 36·73 | 2·18 | 31·89 | 2·62 | .. | .. |
| 14 | 33·63 | 2·20 | 35·39 | 2·13 | .. | .. | 36·04 | 2·23 | .. | .. | 26·89 | 3·12 |
| 15 | 31·64 | 2·39 | 39·25 | 2·75 | 29·31 | 2·04 | 27·81 | 2·55 | 27·87 | 2·58 | 27·84 | 2·80 |
| 16 | 33·09 | 2·71 | 35·38 | 2·32 | 30·76 | 1·91 | 37·52 | 2·50 | 32·81 | 2·79 | 28·34 | 2·22 |
| 17 | 32·59 | 2·43 | 33·34 | 2·83 | 27·85 | 3·10 | 31·99 | 2·93 | 15·56 | 2·72 | 25·71 | 2·54 |
| 18 | 29·09 | 2·85 | 38·99 | 2·05 | 31·01 | 2·06 | 36·67 | 2·22 | 29·48 | 2·17 | 31·11 | 1·77 |
| 19 | 33·46 | 2·58 | 37·06 | 2·18 | 35·31 | 2·38 | 38·70 | 2·61 | 23·79 | 2·60 | 33·22 | 1·93 |
| 20 | 35·64 | 2·89 | 36·45 | 2·43 | 35·92 | 2·72 | 35·36 | 2·43 | 28·48 | 2·56 | 32·31 | 2·57 |
| 21 | .. | .. | .. | .. | .. | .. | 33·16 | 2·69 | 29·83 | 2·82 | 32·90 | 2·94 |
| 22 | 21·95 | 2·72 | 38·80 | 2·58 | 32·60 | 2·27 | 35·19 | 2·26 | 32·81 | 2·67 | .. | .. |
| 23 | 36·64 | 2·77 | 34·92 | 2·06 | 31·22 | 2·23 | 33·47 | 2·37 | 33·65 | 2·45 | 33·86 | 2·66 |
| 24 | 34·69 | 2·98 | 39·02 | 2·19 | 29·28 | 2·55 | 36·14 | 2·35 | 37·94 | 2·49 | .. | .. |
| 25 | 31·62 | 2·85 | 36·07 | 2·21 | 19·25 | 2·21 | 33·83 | 2·45 | 28·09 | 2·79 | 36·27 | 2·35 |
| 26 | 30·69 | 2·72 | 36·10 | 1·82 | 26·92 | 1·68 | .. | .. | 27·70 | 2·02 | 28·54 | 1·99 |
| 27 | 29·36 | 2·82 | 35·48 | 2·48 | .. | .. | 26·14 | 2·63 | 28·23 | 2·46 | 29·10 | 2·36 |
| 28 | 29·42 | 2·86 | 40·90 | 2·17 | 29·82 | 2·62 | 30·54 | 2·31 | 28·73 | 2·38 | 36·76 | 2·85 |
| 29 | .. | .. | 36·26 | 2·22 | .. | .. | 33·02 | 2·23 | 27·53 | 1·95 | 31·23 | 2·13 |
| 30 | 27·40 | 2·89 | 33·81 | 2·68 | 31·67 | 2·85 | 33·94 | 2·24 | 31·89 | 2·13 | 28·11 | 2·31 |
| 31 | 29·45 | 2·94 | 34·46 | 2·42 | 28·58 | 2·48 | 30·60 | 2·49 | 28·86 | 2·23 | 38·37 | 2·12 |
| 32 | 29·26 | 3·04 | 38·67 | 2·19 | 32·42 | 2·39 | 35·80 | 2·16 | 33·28 | 2·43 | .. | .. |
| *Average* | 32·38 | 2·73 | 36·41 | 2·30 | 30·13 | 2·35 | 33·70 | 2·41 | 29·39 | 2·47 | 31·19 | 2·43 |

## INFLUENCE OF ENVIRONMENT ON THE QUALITY OF WHEAT (*cont.*)

| Year | *Ste Anne de la Pocatière, P.Q.* | | *Ottawa, Ont.* | | *Kapuskasing, Ont.* | | *Morden, Man.* | | *Brandon, Man.* | | *Indian Head, Sask.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* | *Weight of 1,000 kernels* | *Nitrogen* |
| | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % |
| 1912 | .. | .. | 35·03 | 2·95 | .. | .. | .. | .. | 35·33 | 3·02 | 35·98 | 2·99 |
| 13 | .. | .. | 34·36 | 2·73 | .. | .. | .. | .. | 32·01 | 2·90 | 35·22 | 2·38 |
| 14 | .. | .. | 33·14 | 2·57 | .. | .. | .. | .. | 28·28 | 3·06 | 31·29 | 2·90 |
| 15 | .. | .. | 24·80 | 3·27 | .. | .. | .. | .. | 32·05 | 3·04 | 34·65 | 2·80 |
| 16 | .. | .. | 31·67 | 2·96 | .. | .. | .. | .. | 21·80 | 2·93 | 33·14 | 2·85 |
| 17 | .. | .. | 31·13 | 2·36 | .. | .. | .. | .. | 31·19 | 2·98 | 30·90 | 3·03 |
| 18 | .. | .. | 31·68 | 2·61 | .. | .. | .. | .. | 35·25 | 2·95 | 35·19 | 2·93 |
| 19 | .. | .. | 33·90 | 2·32 | .. | .. | 26·37 | 3·20 | 26·62 | 2·77 | 30·33 | 2·62 |
| 20 | .. | .. | 36·74 | 2·55 | .. | .. | 32·68 | 2·75 | 28·74 | 3·07 | 32·57 | 2·91 |
| 21 | .. | .. | .. | .. | .. | .. | .. | .. | 24·13 | 2·95 | 21·65 | 2·58 |
| 22 | .. | .. | 32·79 | 2·64 | .. | .. | .. | .. | 35·49 | 3·07 | 33·81 | 2·69 |
| 23 | .. | .. | 38·21 | 2·71 | .. | .. | 24·76 | 2·67 | 18·54 | 2·76 | 23·24 | 2·89 |
| 24 | .. | .. | 36·46 | 2·78 | .. | .. | 36·45 | 2·73 | 28·83 | 2·81 | 30·78 | 2·73 |
| 25 | 38·75 | 2·42 | 35·14 | 2·54 | 29·00 | 2·33 | 27·87 | 2·63 | 25·46 | 2·67 | 31·24 | 2·58 |
| 26 | 36·05 | 2·12 | 35·48 | 2·56 | 31·42 | 1·84 | 25·34 | 2·40 | 29·45 | 2·79 | 32·05 | 2·35 |
| 27 | 40·25 | 2·21 | 36·96 | 3·02 | 30·65 | 1·86 | 25·71 | 2·43 | 25·69 | 2·13 | 33·35 | 2·54 |
| 28 | 35·96 | 2·52 | 32·49 | 2·67 | 32·76 | 1·96 | 27·90 | 3·14 | 38·24 | 2·84 | 34·87 | 2·38 |
| 29 | 37·85 | 2·21 | 27·28 | 2·40 | 30·39 | 2·28 | 31·68 | 2·74 | 27·52 | 2·98 | 28·78 | 2·86 |
| 30 | 36·55 | 2·51 | 31·37 | 2·80 | 15·47 | 2·05 | 29·34 | 2·58 | 25·99 | 2·23 | 27·70 | 2·13 |
| 31 | 30·63 | 2·53 | 30·42 | 3·13 | 39·80 | 2·67 | .. | .. | 31·55 | 3·24 | 32·59 | 3·13 |
| 32 | 36·97 | 2·67 | 31·65 | 2·84 | 26·31 | 2·65 | 34·45 | 3·07 | 32·70 | 2·85 | 25·77 | 3·02 |
| *Average* | 36·63 | 2·40 | 33·04 | 2·73 | 29·48 | 2·21 | 29·32 | 2·76 | 29·28 | 2·86 | 31·20 | 2·73 |

## INFLUENCE OF ENVIRONMENT ON THE QUALITY OF WHEAT (*cont.*)

| Year | Rosthern, Sask. | | Scott, Sask. | | Swift Current, Sask. | | Lethbridge, Alta. | | | | Lacombe, Alta. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Irrigated | | Non-irrigated | | | |
| | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen |
| | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % |
| 1912 | 30·44 | 3·01 | 31·62 | 3·18 | .. | .. | 35·51 | 2·86 | 31·70 | 3·15 | 32·21 | 3·17 |
| 13 | 31·95 | 2·26 | 35·98 | 3·14 | .. | .. | 30·73 | 2·52 | 28·66 | 2·83 | 28·65 | 2·83 |
| 14 | 30·24 | 2·84 | 27·06 | 3·28 | .. | .. | 31·32 | 2·44 | 26·59 | 3·01 | 31·44 | 2·51 |
| 15 | 32·44 | 2·91 | 30·48 | 2·82 | .. | .. | 35·98 | 2·71 | 34·38 | 2·69 | 35·34 | 2·59 |
| 16 | .. | .. | 30·54 | 3·06 | .. | .. | 34·84 | 2·89 | 39·72 | 2·71 | 34·24 | 2·74 |
| 17 | 32·79 | 3·03 | 27·38 | 3·12 | .. | .. | 33·48 | 2·59 | 26·11 | 2·95 | 34·76 | 2·49 |
| 18 | 34·65 | 3·14 | 27·41 | 3·55 | .. | .. | .. | .. | .. | .. | 31·94 | 2·98 |
| 19 | .. | .. | 26·89 | 2·78 | .. | .. | 38·05 | 2·62 | 26·45 | 2·48 | 36·61 | 2·71 |
| 20 | 33·11 | 3·06 | 33·48 | 3·06 | .. | .. | 40·08 | 2·86 | 24·96 | 2·60 | 37·39 | 2·63 |
| 21 | 31·85 | 3·23 | 30·25 | 3·22 | .. | .. | 30·58 | 2·89 | 22·68 | 3·05 | 31·61 | 2·87 |
| 22 | 31·14 | 2·96 | .. | .. | .. | .. | 27·93 | 2·59 | 31·40 | 2·92 | 31·29 | 3·24 |
| 23 | 29·64 | 2·98 | 28·08 | 2·84 | .. | .. | 36·00 | 2·85 | 31·60 | 2·54 | 37·62 | 3·05 |
| 24 | 27·99 | 2·94 | 26·33 | 3·01 | .. | .. | 33·87 | 2·85 | 26·78 | 3·17 | .. | .. |
| 25 | 34·26 | 2·66 | 34·24 | 2·87 | .. | .. | 36·94 | 2·70 | 22·17 | 3·47 | 34·64 | 2·70 |
| 26 | 26·73 | 2·93 | 27·17 | 3·22 | 25·90 | 3·15 | 36·41 | 2·70 | 26·84 | 3·03 | 34·96 | 2·66 |
| 27 | 28·85 | 2·55 | 30·16 | 2·73 | 30·80 | 2·70 | 36·40 | 2·75 | 29·65 | 2·39 | .. | .. |
| 28 | 40·13 | 2·91 | 31·06 | 2·97 | 32·78 | 2·90 | 39·76 | 2·71 | 35·80 | 2·75 | 31·31 | 2·59 |
| 29 | 26·78 | 3·24 | 25·44 | 3·47 | 20·25 | 3·84 | 38·43 | 2·21 | 21·64 | 3·64 | 30·28 | 2·75 |
| 30 | 33·40 | 2·68 | 30·31 | 2·80 | 26·34 | 3·15 | 36·14 | 3·05 | 29·81 | 2·92 | 36·42 | 2·99 |
| 31 | 30·96 | 3·23 | 31·84 | 2·98 | .. | .. | 33·98 | 2·92 | 27·48 | 2·92 | 35·82 | 2·47 |
| 32 | 28·28 | 3·13 | 29·91 | 3·00 | 31·70 | 3·38 | 33·25 | 3·08 | 26·27 | 2·98 | 30·20 | 3·09 |
| *Average* | 31·35 | 2·92 | 29·79 | 3·06 | 28·28 | 3·19 | 34·98 | 2·74 | 28·53 | 2·91 | 33·51 | 2·79 |

## INFLUENCE OF ENVIRONMENT ON THE QUALITY OF WHEAT (*cont.*)

| Year | Fort Vermilion, Alta. | | Invermere (Windermere), B.C. | | | | Summerland, B.C. | | Agassiz, B.C. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Irrigated | | Non-irrigated | | | | | |
| | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen |
| | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % |
| 1912 | .. | .. | .. | .. | .. | .. | .. | .. | 40·72 | 2·59 |
| 13 | .. | .. | .. | .. | .. | .. | .. | .. | 34·38 | 3·33 |
| 14 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 15 | .. | .. | .. | .. | 33·97 | 1·96 | .. | .. | 38·59 | 2·77 |
| 16 | .. | .. | 37·41 | 1·88 | 33·94 | 2·83 | .. | .. | 38·35 | 2·79 |
| 17 | .. | .. | 24·57 | 2·42 | 22·57 | 3·47 | .. | .. | 35·36 | 3·23 |
| 18 | 35·44 | 3·14 | .. | .. | 31·80 | 2·83 | 32·84 | 2·05 | 37·07 | 2·42 |
| 19 | 35·04 | 2·33 | 40·68 | 2·01 | 28·45 | 3·22 | 29·45 | 3·18 | 32·94 | 1·87 |
| 20 | 30·35 | 3·15 | 34·25 | 2·21 | 21·10 | 3·18 | 38·24 | 2·65 | 36·30 | 2·35 |
| 21 | 38·46 | 2·14 | 36·96 | 2·65 | 23·30 | 3·06 | 33·57 | 2·54 | 43·18 | 2·51 |
| 22 | 37·51 | 2·94 | 37·69 | 2·44 | 26·33 | 2·75 | 36·84 | 2·73 | .. | .. |
| 23 | 40·06 | 2·34 | 34·09 | 2·52 | 27·77 | 3·16 | .. | .. | .. | .. |
| 24 | 38·33 | 2·15 | 38·61 | 2·89 | .. | .. | .. | .. | 36·61 | 2·34 |
| 25 | 36·86 | 2·81 | 42·78 | 2·61 | .. | .. | 28·74 | 2·41 | 35·87 | 2·29 |
| 26 | 36·35 | 3·02 | 35·15 | 2·44 | 21·99 | 3·41 | 30·68 | 3·11 | 37·41 | 2·74 |
| 27 | 36·28 | 2·75 | 28·53 | 2·81 | 26·69 | 3·13 | .. | .. | 35·33 | 2·82 |
| 28 | 33·74 | 2·78 | 27·03 | 2·74 | 26·43 | 3·09 | .. | .. | 37·77 | 3·36 |
| 29 | 34·64 | 2·78 | 37·41 | 2·19 | 20·11 | 3·34 | .. | .. | 39·82 | 3·17 |
| 30 | 33·69 | 3·31 | .. | .. | .. | .. | .. | .. | 41·94 | 2·72 |
| 31 | 37·83 | 2·88 | 38·70 | 2·93 | 26·47 | 3·24 | .. | .. | 34·24 | 2·34 |
| 32 | 37·83 | 2·35 | .. | .. | .. | .. | .. | .. | 21·32 | 2·68 |
| *Average* | 36·16 | 2·73 | 35·28 | 2·48 | 26·50 | 3·05 | 32·91 | 2·61 | 36·51 | 2·68 |

## APPENDIX B

### INFLUENCE OF ENVIRONMENT

*Marquis Wheat. Average Weight of Kernels: Average Nitrogen (Dry-matter Basis)*

(Arranged geographically)

*Experimental Farms and Stations, 1912–32*

| *Experimental farm or station* | *Number of samples* | *Average weight of 1,000 kernels* | *Average nitrogen* |
|---|---|---|---|
| | | gm. | % |
| Parent-seed, Indian Head, Sask. | 19 | 32·38 | 2·73 |
| Charlottetown, P.E.I. | 20 | 36·41 | 2·30 |
| Kentville, N.S. | 15 | 30·13 | 2·35 |
| Nappan, N.S. | 20 | 33·70 | 2·41 |
| Fredericton, N.B. | 19 | 29·39 | 2·47 |
| Cap Rouge, P.Q. | 17 | 31·19 | 2·43 |
| Ste Anne de la Pocatière, P.Q. | 8 | 36·63 | 2·40 |
| Ottawa, Ont. | 20 | 33·04 | 2·73 |
| Kapuskasing, Ont. | 8 | 29·48 | 2·21 |
| Morden, Man. | 11 | 29·32 | 2·76 |
| Brandon, Man. | 21 | 29·28 | 2·86 |
| Indian Head, Sask. | 21 | 31·20 | 2·73 |
| Rosthern, Sask. | 19 | 31·35 | 2·92 |
| Scott, Sask. | 20 | 29·79 | 3·06 |
| Swift Current, Sask. | 10 | 28·28 | 3·19 |
| Lethbridge, Alta. (irrigated) | 20 | 34·98 | 2·74 |
| " " (non-irrigated) | 20 | 28·53 | 2·91 |
| Lacombe, Alta. | 19 | 33·51 | 2·79 |
| Fort Vermilion, Alta. | 15 | 36·16 | 2·73 |
| Invermere (Windermere) (irrigated) | 14 | 35·28 | 2·48 |
| " " (non-irrigated) | 14 | 26·50 | 3·05 |
| Summerland, B.C. | 7 | 32·91 | 2·69 |
| Agassiz, B.C. | 18 | 36·51 | 2·68 |

## INFLUENCE OF ENVIRONMENT ON THE QUALITY OF WHEAT (*cont.*)

| Year | Fort Vermilion, Alta. | | Invermere (Windermere), B.C. | | | | Summerland, B.C. | | Agassiz, B.C. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Irrigated | | Non-irrigated | | | | | |
| | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen | Weight of 1,000 kernels | Nitrogen |
| | gm. | % | gm. | % | gm. | % | gm. | % | gm. | % |
| 1912 | .. | .. | .. | .. | .. | .. | .. | .. | 40·72 | 2·59 |
| 13 | .. | .. | .. | .. | .. | .. | .. | .. | 34·38 | 3·33 |
| 14 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 15 | .. | .. | .. | .. | 33·97 | 1·96 | .. | .. | 38·59 | 2·77 |
| 16 | .. | .. | 37·41 | 1·88 | 33·94 | 2·83 | .. | .. | 38·35 | 2·79 |
| 17 | .. | .. | 24·57 | 2·42 | 22·57 | 3·47 | .. | .. | 35·36 | 3·23 |
| 18 | 35·44 | 3·14 | .. | .. | 31·80 | 2·83 | 32·84 | 2·05 | 37·07 | 2·42 |
| 19 | 35·04 | 2·33 | 40·68 | 2·01 | 28·45 | 3·22 | 29·45 | 3·18 | 32·94 | 1·87 |
| 20 | 30·35 | 3·15 | 34·25 | 2·21 | 21·10 | 3·18 | 38·24 | 2·65 | 36·30 | 2·35 |
| 21 | 38·46 | 2·14 | 36·96 | 2·65 | 23·30 | 3·06 | 33·57 | 2·54 | 43·18 | 2·51 |
| 22 | 37·51 | 2·94 | 37·69 | 2·44 | 26·33 | 2·75 | 36·84 | 2·73 | .. | .. |
| 23 | 40·06 | 2·34 | 34·09 | 2·52 | 27·77 | 3·16 | .. | .. | .. | .. |
| 24 | 38·33 | 2·15 | 38·61 | 2·89 | .. | .. | .. | .. | 36·61 | 2·34 |
| 25 | 36·86 | 2·81 | 42·78 | 2·61 | .. | .. | 28·74 | 2·41 | 35·87 | 2·29 |
| 26 | 36·35 | 3·02 | 35·15 | 2·44 | 21·99 | 3·41 | 30·68 | 3·11 | 37·41 | 2·74 |
| 27 | 36·28 | 2·75 | 28·53 | 2·81 | 26·69 | 3·13 | .. | .. | 35·33 | 2·82 |
| 28 | 33·74 | 2·78 | 27·03 | 2·74 | 26·43 | 3·09 | .. | .. | 37·77 | 3·36 |
| 29 | 34·64 | 2·78 | 37·41 | 2·19 | 20·11 | 3·34 | .. | .. | 39·82 | 3·17 |
| 30 | 33·69 | 3·31 | .. | .. | .. | .. | .. | .. | 41·94 | 2·72 |
| 31 | 37·83 | 2·88 | 38·70 | 2·93 | 26·47 | 3·24 | .. | .. | 34·24 | 2·34 |
| 32 | 37·83 | 2·35 | .. | .. | .. | .. | .. | .. | 21·32 | 2·68 |
| *Average* | 36·16 | 2·73 | 35·28 | 2·48 | 26·50 | 3·05 | 32·91 | 2·61 | 36·51 | 2·68 |

## APPENDIX B

### INFLUENCE OF ENVIRONMENT

*Marquis Wheat. Average Weight of Kernels: Average Nitrogen (Dry-matter Basis)*

(Arranged geographically)

*Experimental Farms and Stations, 1912–32*

| *Experimental farm or station* | *Number of samples* | *Average weight of 1,000 kernels* | *Average nitrogen* |
|---|---|---|---|
| | | gm. | % |
| Parent-seed, Indian Head, Sask. | 19 | 32·38 | 2·73 |
| Charlottetown, P.E.I. | 20 | 36·41 | 2·30 |
| Kentville, N.S. | 15 | 30·13 | 2·35 |
| Nappan, N.S. | 20 | 33·70 | 2·41 |
| Fredericton, N.B. | 19 | 29·39 | 2·47 |
| Cap Rouge, P.Q. | 17 | 31·19 | 2·43 |
| Ste Anne de la Pocatière, P.Q. | 8 | 36·63 | 2·40 |
| Ottawa, Ont. | 20 | 33·04 | 2·73 |
| Kapuskasing, Ont. | 8 | 29·48 | 2·21 |
| Morden, Man. | 11 | 29·32 | 2·76 |
| Brandon, Man. | 21 | 29·28 | 2·86 |
| Indian Head, Sask. | 21 | 31·20 | 2·73 |
| Rosthern, Sask. | 19 | 31·35 | 2·92 |
| Scott, Sask. | 20 | 29·79 | 3·06 |
| Swift Current, Sask. | 10 | 28·28 | 3·19 |
| Lethbridge, Alta. (irrigated) | 20 | 34·98 | 2·74 |
| " " (non-irrigated) | 20 | 28·53 | 2·91 |
| Lacombe, Alta. | 19 | 33·51 | 2·79 |
| Fort Vermilion, Alta. | 15 | 36·16 | 2·73 |
| Invermere (Windermere) (irrigated) | 14 | 35·28 | 2·48 |
| " " (non-irrigated) | 14 | 26·50 | 3·05 |
| Summerland, B.C. | 7 | 32·91 | 2·69 |
| Agassiz, B.C. | 18 | 36·51 | 2·68 |

## APPENDIX C

### INFLUENCE OF ENVIRONMENT

*Marquis Wheat. Average Weight of Kernels: Average Nitrogen (Dry-matter Basis)*

(Arranged according to Nitrogen-content)

*Experimental Farms and Stations, 1912–32*

| *Experimental farm or station* | *Number of samples* | *Average nitrogen* |
|---|---|---|
| | | % |
| Group 1. Range of Nitrogen-content 3·19–2·68% | | |
| Swift Current, Sask. | 10 | 3·19 |
| Scott, Sask. | 20 | 3·06 |
| Invermere (Windermere), B.C. (non-irrigated) | 14 | 3·05 |
| Rosthern, Sask. | 19 | 2·92 |
| Lethbridge, Alta. (non-irrigated) | 20 | 2·91 |
| Brandon, Man. | 21 | 2·86 |
| Lacombe, Alta. | 19 | 2·79 |
| Morden, Man. | 11 | 2·76 |
| Parent-seed, Indian Head, Sask. | 19 | 2·73 |
| Indian Head, Sask. | 21 | 2·73 |
| Fort Vermilion, Alta. | 15 | 2·73 |
| Ottawa, Ont. | 20 | 2·73 |
| Summerland, B.C. | 7 | 2·69 |
| Agassiz, B.C. | 18 | 2·68 |
| Group 2. Range of Nitrogen-content 2·48–2·21% | | |
| Invermere (Windermere), B.C. (irrigated) | 14 | 2·48 |
| Fredericton, N.B. | 19 | 2·47 |
| Cap Rouge, P.Q. | 17 | 2·43 |
| Nappan, N.S. | 20 | 2·41 |
| Ste Anne de la Pocatière, P.Q. | 8 | 2·40 |
| Kentville, N.S. | 15 | 2·35 |
| Charlottetown, P.E.I. | 20 | 2·30 |
| Kapuskasing, Ont. | 8 | 2·21 |

This investigation has furnished evidence that environmental factors, chiefly rainfall and temperature during the latter weeks of the development of the grain, may affect the protein-content ($N \times 5{\cdot}7$) by as much as 5·59 per cent.

# CHANGES AND EVENTS IN A LARGE DAIRY HERD FROM 1912 TO 1932

J. HUNTER-SMITH
(*Principal, Herts. Institute of Agriculture*)

## PT. I. *Introduction*

THE briefest description of the herd from which the following records were obtained must suffice. Starting in 1912 with some three dozen, mainly commercial, cows, the herd has increased in size till after twenty years the number exceeds seventy.

*Herd policy* has aimed consistently at the marketing of regular but increasing quantities of milk, at capital appreciation of the stock by grading up with pedigree bulls, and at the replacement of all cows drafted out by heifers bred on the farm.

The *milk-yields* of full-time cows have never since 1919–20 fallen below an average of 700 gallons, and have exceeded 1,000 gallons per cow during the past few years.

The *management* of the herd has been consistently progressive and has involved the adoption of a modified 'Boutflour' system in recent years. Of special interest is the control of calving dates as summarized below and contrasted with the results obtained in certain other milk-selling herds.

*Percentage of Cows which calved in Different Months of the Year*

| *Herd* | *May* | *June* | *July* | *Aug.* | *Sept.* | *Oct.* | *Nov.* | *Dec.* | *Jan.* | *Feb.* | *Mar.* | *Apr.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (940 calvings) | 2·4 | 8·5 | 9·7 | 9·0 | 10·1 | 11·9 | 13·5 | 13·4 | 9·8 | 6·2 | 4·5 | 1·0 |
| | | 20·6 | | | 31·0 | | | 36·7 | | | 11·8 | |
| *Essex* (*a*) | 6·1 | 9·8 | 10·8 | 7·9 | 4·7 | 8·8 | 7·3 | 10·1 | 9·6 | 12·4 | 7·4 | 5·1 |
| (1,418 cows) | | 26·7 | | | 21·4 | | | 27·0 | | | 24·9 | |

(*a*) See *J. Royal Agric. Soc. England*, 1912, **73**, 170.

In five of the twenty years no calves were born in the two months April and May; April was a blank month in twelve of the years, and May in ten.

*Breeding* for high milk-yields has met with substantial success, as evidenced by the following results:

| *Bull* | *Number of dam/daughter comparisons* | *Average mature lactation yields* (*a*) *of* | |
|---|---|---|---|
| | | *Dams* | *Daughters* |
| | | *lb.* | *lb.* |
| A | 60 | 8,924 | 8,799 |
| B | 33 | 8,560 | 10,636 |
| C | 7 | 8,738 | 7,983 |
| D | 12 | 8,430 | 13,065 |

(*a*) These figures indicate that the deep-milking qualities of the dams are well maintained by the progeny.

The whole of the data analysed in the following pages has been extracted from the records kept by the farmer to help him in the control of his business. The simplicity of the system and the accuracy of the entries are worthy both of praise and of imitation.

## Pt. II. *Births and the Maintenance of the Herd*

In the herd there was a total of 940 births. Of these 875, or 93 per cent., were singles and the remainder, with the exception of one group of triplets, were twins. Of the calves 483 were bulls, but the number is increased to 504½ by adding half of the 43 foetuses of unknown sex. Eighty per cent. of the bulls were sold, either as stores (in the early years) or as calves; 3 per cent. died and 17 per cent. were born dead or died at birth.

*Sex-ratio.*—From Table 1 it will be noticed that, as might be expected over so long a period, the calves were almost equally divided between the sexes. But this equality in the sex-ratio conceals wide variations in individual years. There were in fact two periods, each of three successive years, when heifer calves were substantially under-represented, the ratios being just under and just over two heifers to three bulls respectively. Further, these two periods were each followed by two years of approximate equality of sexes, before the balance was restored by a high proportion of heifers for similar three-year periods.

Table 1. *Single Births and Heifers reared*

| | *Number of calves* | | | | *Heifers reared and calving in herd* | | |
|---|---|---|---|---|---|---|---|
| *Period* | *Heifers* | *Bulls* | *Sex unknown* | *Total* | *Number* | *% of total* | *% of (a) heifers* |
| 5 yrs. 1912–17 . . | 77 | 94 | 1 | 172 | 52 | 30 | 67 |
| 5 yrs. 1917–22 . . | 97 | 88 | 1 | 186 | 70 | 38 | 72 |
| 5 yrs. 1922–7 . . | 103 | 123 | 9 | 235 | 74 | 31 | 69 |
| 5 yrs. 1927–32 . . | 149 | 124 | 9 | 282 | 99 (*b*) | 35 | 65 |
| 20 yrs. 1912–32 . . | 426 | 429 | 20 | 875 | 295 (*b*) | 34 | 68 |
| 17 yrs. 1912–29 . . | 324 | 357 | 19 | 700 | 226 (*b*) | 32 | 68 |

(*a*) Half of the calves of unknown sex have been reckoned as heifers.
(*b*) It has been assumed that 68 per cent. of 102 heifer calves born in the three years 1929–32 will ultimately reach the herd, and this number has been added to the 30 heifer calves born in 1927–9 which are known to have reached the herd.

*Single births and heifers reared.*—In Table 1 it is seen that 226 heifers were brought into the milking herd in seventeen years, an average of approximately 13 per annum. This, as will be seen later, compares with disposals from the milking herd at the average rate of 11 per annum. The difference, 2 per annum, represents the rate at which the herd has increased in size. Ten heifer calves have been required to provide nearly 7 dairy cows, while 32 per cent. of all the single births were duly brought into the herd. The latter figure is, however, slightly distorted by the higher proportion of bull calves at the end of seventeen years. The appropriate figure for the whole period of twenty years, when the sex-ratio was equal, may be calculated by assuming that 68 per cent. of the heifer calves

born in the three years 1929–32 will ultimately reach the herd. On this basis, 34 per cent. of all the calves become dairy cows. There were, however, wide variations in individual years; for example, the proportion of single heifer calves to reach the herd has varied from as low a figure as 43 per cent. to as high as 90 per cent., and of all single births from 15 per cent. to 50 per cent.

*Multiple births and heifers reared.*—From Table 2 it is apparent that multiple births have increased in frequency. In the first period the proportion was one multiple birth to 25 single births, in the last period it was one to 13½. In terms of calves the proportions were 9 per cent. and nearly 20 per cent. respectively, so that the number of animals involved became considerable.

TABLE 2. *Multiple Births and Heifers reared*

| | *Number of calves* | | | | | *Heifers reared and calving in herd* | | |
|---|---|---|---|---|---|---|---|---|
| *Period* | *Heifers* | | *Bulls* | *Sex unknown* | *Total* | *Number* | *% of total* | *% of heifers* |
| | (*a*) | (*b*) | | | | | | (*c*) |
| 5 yrs. 1912–17 | 2 | 1 | 1 | 11 | 15 | .. | .. | .. |
| 5 yrs. 1917–22 | 4 | 6 | 16 | .. | 26 | 2 | 8 | 20 |
| 5 yrs. 1922–7 | 8 | 6 | 8 | 10 | 32 | 2 | 6 | 11 |
| 5 yrs. 1927–32 | 14 | 13 | 29 | 2 | 58 | .. | .. | .. |
| 20 yrs. 1912–32 | 28 | 26 | 54 | 23 | 131 | .. | .. | .. |
| 17 yrs. 1912–29 | 14 | 16 | 34 | 23 | 87 | 4 | 5 | 10 |

(*a*) Twin to heifers. (*b*) Twin to bulls.
(*c*) Half of the calves of unknown sex are assumed to have been heifers, and half of these to have been twin to bulls.

Very few twin heifer calves—only four out of 41½, or 10 per cent.—survived to join the milking herd. It may be assumed, however, that heifers that were twin to bulls were purposely rejected; on this assumption 20 per cent. of the possible breeders reached the herd, compared with 70 per cent. in the case of singles. There is some indication of better results from the larger number of examples in recent years, but meanwhile it remains true that only 4 per cent. of the 87 calves resulting from multiple births assumed the role of milk producers.

*All births and heifers reared.*—In preparing Table 3, which summarizes the position with regard to the proportion of heifer calves that reach the

TABLE 3. *All Births and Heifers reared*

| | *Numbers* | | *Heifers reared and calving in herd* | | |
|---|---|---|---|---|---|
| | *All calves* | *Heifers* | *Number* | *% of total* | *% of heifers* |
| Singles | 875 | 436 | 295 | 34 | 68 |
| Twins | 128 | 64 | 9 (*a*) | 7 | 14 |
| Triplets | 3 | 1½ | .. | .. | .. |
| *Total* | 1,006 | 501½ | 304 | 30 | 60 |

(*a*) Five of the 8 calves born in 1929–32 are included.

herd, two main assumptions have been made, first, that half the calves of unknown sex were heifers, and second, that 70 per cent. of the heifer calves born in the three years 1929–32 will in due course reach the herd. The final results thus obtained agree very closely with the actual figures for a period of seventeen years.

In round figures, 10 calves or 5 heifer calves were required to produce 3 dairy cows. This conclusion and the variations that occurred from year to year are a fitting introduction to the examination of the causes of the wastage that occurred.

*Wastage of calves and heifers.*—The recorded data on the causes of wastage in single heifers are summarized below in Table 4:

TABLE 4. *Wastage* (*Single Heifers*)

| *Years:* | *1912–17* | *1917–22* | *1922–7* | *1927–32* | *Total* |
|---|---|---|---|---|---|
| *Cause* | *No.* | *No.* | *No.* | *No.* | *No.* |
| Abortion, dead at birth, and half unknown sex | 2½ | 3½ | 11½ | 22½ | 40 |
| Died within 14 days of birth | 5 | 1 | 5 | 5 | 16 |
| Died 14 days to 18 months old | 3 | .. | 3 | 1 | 7 |
| Sold as 'wasters', 'bad doers', or at low prices | 4 | 14 | 8 | 5 | 31 |
| Sold barren, about 3 years old | 5 | 2 | 4 | .. | 11 |
| Sold at normal prices | .. | 5 | 1 | 4 | 10 |
| Sold for various reasons | 1 | .. | 1 | 4 | 6 |
| No information | 5 | 2 | .. | .. | 7 |
| *Total* | 25½ | 27½ | 33½ | 41½ | 128 |
| All single heifer calves | 77½ | 97½ | 107½ | 153½ | 436 |
| Minimum wastage (excluding normal sales and reasons not stated) per cent. | 26 | 21 | 30 | 25 | 25 |

It is apparent from the above table that abortion has been responsible for nearly one-third of the losses and that, even allowing for the increased size of the herd, the incidence of the disease has increased. Deaths occur mainly among quite young animals and number 23 or about 5 per cent. of the total; 'wasters' and 'bad doers' are, next to abortion, the main source of loss, accounting between them for 25 per cent. of the total wastage. There were 10 wasters, 5 of which realized in the prime of their youth (average age 2 years 4 months) less than £6 each, whilst 15 out of 17 described as bad doers were sold for just over £9 each (average age 1 year 10 months). Losses for these two reasons have apparently been reduced in recent years, but it must be remembered that full opportunity for loss has not been afforded in the case of calves born between 1929 and 1932. Similarly the incidence of sterility may not be fully shown in the last period.

Five of the animals sold at normal prices were disposed of as calves, whilst of those sold for various reasons one died as a result of being 'blown', another in consequence of 'scour', and four from lead poisoning.

Although the data are not quite complete, the final column in the table

seems to be a fair representation of the losses that have occurred. Over a long period of years in a herd which has been visited by both abortion and tuberculosis, but which has been singularly free from scour and other ailments of calves, the wastage among single heifer calves between birth and the age at which they might be expected to come into the herd has been not less than 25 per cent.

Serious as is the above loss it is insignificant compared with the losses that occurred in calves born as twins or triplets. During the twenty years multiple births were responsible for 131 calves, of which 54 were identified as heifers and to this number can be added half of the 23 of unknown sex, making 65½ in all. The tragic history of these animals is as follows: 29½ were 'born dead', 21 were twins to bull calves and were sold young, 2 were sold as 'barreners', 1 as a bad doer, and only 4 actually entered the herd in the course of seventeen years. Eight others born in 1929–32 have still a chance of becoming milk producers.

The above results from calves of single and multiple birth are brought together in Table 5:

TABLE 5. *Wastage of Calves and Heifers. Summary*

| *Cause* | *Singles* | | *Multiples* | | *Total* | |
|---|---|---|---|---|---|---|
| | *No.* | % | *No.* | % | *No.* | % |
| Abortion (dead at birth) | 40 | 31 | 29½ | 55 | 69½ | 38½ |
| Died | 23 | 18 | .. | .. | 23 | 12½ |
| Disease (including sterility) | 44 | 34½ | 3 | 6 | 47 | 26 |
| Accident | 4 | 3 | .. | .. | 4 | 2 |
| Heifers twin to bulls | .. | .. | 21 | 39 | 21 | 11½ |
| Trade | 10 | 8 | .. | .. | 10 | 5½ |
| Not stated | 7 | 5½ | .. | .. | 7 | 4 |
| *All* | 128 | 100 | 53½ | 100 | 181½ | 100 |
| All animals in group | 436 | | 65½ | | 501½ | |
| Minimum wastage (excluding trade and not stated) per cent. | 25 | | 82 | | 33 | |

This table requires little explanation. The heavy incidence of abortion and other diseases is apparent, the former to the exclusion of most other factors in the case of twins. The minimum percentage wastage has been calculated in the way previously described, and shows how enormous are the losses among twins. Finally, the total losses from all heifer calves are shown to be not less than 33 per cent. of the whole heifer population. This conclusion may be compared with the previous statement that 5 heifer calves were required to produce 3 milking cows, which implies that 40 per cent. of these calves failed to reach the herd. At least 33 of the 40 have now been definitely associated with unwelcome wastage, so that the formula can be stated in slightly more elastic terms, namely, that 15 heifer calves were required to produce between 9 and 10 milking cows.

*Incidence of abortion and dead at birth.*—Before concluding this section of the paper, it seems desirable to present a summary of the extent to which premature or still-born births occurred, leaving the discussion of

the effects of abortion to a later stage. It may be observed that although the term 'abortion' has figured prominently in previous tables, there is no reason to assume that this herd has suffered more in this respect than the average. Admittedly serious losses occurred, but, on the other hand, during the whole of the twenty years there was no kind of epidemic resulting in an interruption of commercial or breeding policies. Nevertheless, abortion is specifically mentioned as having occurred in sixteen out of the twenty years, whilst the number of cases in any year has varied from nil to eleven. The mass results are shown in Table 6:

TABLE 6. *Incidence of Abortion and Dead at Birth*

| | | *All calves* | *Abortion and dead at birth* | |
|---|---|---|---|---|
| | | | *Number* | *Percentage* |
| Singles: | Heifers | 436 | 43 (*a*) | 10 |
| | Bulls | 439 | 64 | 15 |
| | *Total* | 875 | 107 | 12 |
| Multiples: | Heifers | 65½ | 22 | 34 |
| | Bulls | 65½ | 23 | 35 |
| | *Total* | 131 | 45 (*b*) | 34 |
| *All* | | 1,006 | 152 | 15 |

(*a*) Includes 3 heifer calves which were reared although born prematurely at 8 months.

(*b*) Includes 18 twins, 1 triplet, and 6 cases in which one of twins was born dead.

Thus 15 per cent. of all the calves born in the herd were still-born, losses of singles amounting to 12 per cent., and of multiples to 34 per cent.

## PT. III. *The Dairy Herd*

*The age of cows in the herd and of cows drafted out of the herd.*—Table 7 presents an accurate picture of the age-composition of the herd from time to time. The average number of cows in the herd for any period was determined from the farmer's own records. Cows as they calved were entered in the book, so that each year's records gave the total number of cows calving in any year—the year beginning with May and ending in April; but, as cows which calved in one year and not in the next did not appear in the annual list, certain corrections were necessary. Finally, the numbers were checked from year to year by adding on heifers and deducting drafts. Any errors which occurred were very trifling.

A glance at the top and bottom lines of the table shows a steady increase in the size of the herd and a remarkable consistency in its age-composition. In each period first calvers are the largest class and in each period first and second calvers constitute at least half the herd. The other half is divided almost equally between cows in their prime (third and fourth calvers) and older cows. At no time have cows that have had 10 to 13

TABLE 7. *Percentage Numbers of Cows of Various Ages (in Lactations)*

| | *In the herd* | | | | | *Drafted out of the herd* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Years:* | *1912–17* | *1917–22* | *1922–7* | *1927–32* | *All* | *1912–17* | *1917–22* | *1922–7* | *1927–32* | *All* |
| *No. of cows* | 179 | 196 | 271 | 346 | 992 | 43 | 57 | 53 | 72 | 225 |
| *Age of cows (in lactations)* | % | % | % | % | % | % | % | % | % | % |
| 1 | 30 | 31 | 28 | 28 | 29 | 21 | 28 | 17 | 15 | 20 |
| 2 | 24 | 20 | 25½ | 22 | 22½ | 23½ | 33 | 21 | 21 | 24 |
| 3 | 16 | 9 | 16 | 15½ | 14½ | 14 | 9 | 19 | 17 | 15 |
| 4 | 8 | 9 | 12 | 9½ | 10 | 9 | 3½ | 15 | 8 | 9 |
| 5 | 7 | 9 | 7½ | 8 | 8 | 7 | 9 | 7 | 12 | 9 |
| 6 | 4½ | 8 | 4 | 7 | 5½ | 7 | 7½ | 6 | 10 | 8 |
| 7 | 3 | 6 | 1 | 5 | 4 | 2½ | 3½ | 2 | 10 | 5 |
| 8 | 3 | 4 | 2 | 2 | 2½ | 4½ | 5 | 2 | 4 | 4 |
| 9 | 1 | 2 | 1 | 1½ | 2 | 2½ | 2 | 2 | .. | 1 |
| 10, 11, 12, 13 | 3½ | 2 | 3 | 1½ | 2 | 9 | .. | 9 | 3 | 5 |
| | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| *Average Age (in lactations)* | 3·1 | 3·4 | 3·0 | 3·2 | 3·17 *Fig. 1* | 4·0 | 3·0 | 4·0 | 4·0 | 3·7 *Fig. 1* |

calves been absent and animals of this age have, in fact, been required in the pursuance of the self-supporting policy. The practical application of this policy has resulted in the retention of all cows to the very limit of their useful commercial life. Why then is the average age of the animals in the herd so low as 3 calvings in one period, and never higher than 3·4 calvings, with an average for twenty years of just under 3·2 calvings per cow? An introduction to the answer is provided by the examination of the data in the right-hand columns of the table. There it is seen that as the herd increased in size so did the number of drafts. Second calvers provide the biggest proportions but only slightly more than first calvers. From these two age-groups, just short of half the drafts were forthcoming—surely a most serious result, especially as low milk-yields play no part whatever in its determination. Cows in their prime (third and fourth calvers) constitute, on the average, one quarter of the drafts, an exactly similar representation to the proportion of these ages in the herd, whilst, as might be expected, there is an increased proportion of old cows in the drafts.

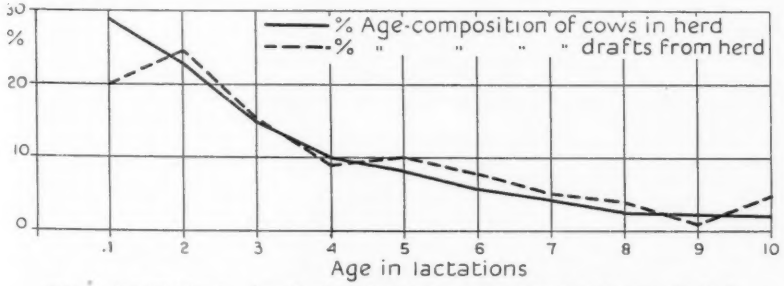


FIG. 1 (cf. Table 7). Age (in lactations) of cows retained and cows drafted.

The striking result is that disposals from the herd are found in every age-group, and the greater the number of animals represented in any group

the greater is the wastage. No age has been immune, not even heifers just introduced into the herd; on the other hand, there were survivors in each age-group, including that of cows which had produced 8 or 9 calves.

In the final result for the four periods, the average age of the animals drafted out of the herd varied from 3 to 4 calvings with an average of 3·7. As the equivalent figure for cows in the herd was 3·17, the margin for increase is no more than that represented by half a lactation. In one period the drafts were actually younger than the age average of the herd, and if that relationship had continued the self-supporting policy would have failed. Indeed every heifer and every old cow that justified retention by her general fitness has been required to maintain that policy with just a very small margin to spare.

Before proceeding to examine the causes responsible, it is possible to get a clearer picture of the incidence of the wastage by setting out in tabular form the ratio between the number of drafts from the herd in each age-group in each period to the number of animals actually represented in each group. This is done in Table 8.

TABLE 8. *Ratio of Number in Herd to Number of Drafts*

| *Years:* | *1912–17* | | *1917–22* | | *1922–7* | | *1927–32* | | *All* | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Age of cows (in lactations)* | *Numbers* | *Ratio* | *Numbers* | *Ratio* | *Numbers* | *Ratio* | *Numbers* | *Ratio* | *Numbers* | *Ratio* |
| 1 | 54/9 | 6 | 61/16 | 4 | 76/9 | 8½ | 97/11 | 9 | 288/45 | 6½ |
| 2 | 42/10 | 4 | 40/19 | 2 | 69/11 | 6 | 75/15 | 5 | 226/55 | 4 |
| 3 | 29/6 | 5 | 17/5 | 3½ | 44/10 | 4½ | 54/12 | 4½ | 144/33 | 4 |
| 4 | 16/4 | 4 | 17/2 | 8½ | 33/8 | 4 | 33/6 | 5½ | 99/20 | 5 |
| 5 | 12/3 | 4 | 18/5 | 3½ | 20/4 | 5 | 28/9 | 3 | 78/21 | 4 |
| 6/7 | 13/4 | 3 | 27/6 | 4½ | 13/4 | 3 | 41/14 | 3 | 94/28 | 3½ |
| 8/9 | 7/3 | 2 | 13/4 | 3 | 8/2 | 4 | 15/3 | 4 | 41/12 | 3½ |
| 10+ | 6/4 | 1½ | .. | .. | 8/5 | 1½ | 5/2 | 2½ | 22/11 | 2 |
| *Average* | 179/43 | 4 | 196/57 | 3½ | 271/53 | 5 | 346/72 | 5 | 992/225 | 4½ |

There is thus a fair degree of similarity between the four periods: the first approximates closely to the general average, the second is worse (especially with regard to heifers and young cows), whilst the third and fourth have in most of the age-groups a higher survival rate. The final average for the whole period is represented by the ratio 4½ to 1, or an annual wastage of 2 animals out of 9. Heifers show up favourably except in the five years from 1917 to 1922, whilst with one exception the rate of wastage among second to fifth calvers varies within narrow limits from 1 in 5 to 1 in 3½ or very little less than the final average of 1 in 4½. It is only with cows that have had more than 5 calves that the rate increases appreciably, and even then only very gradually till after the ninth calf. The persistence of a few aged cows is indeed remarkable.

The outstanding feature of the table is the consistency of the wastage in each age-group. This is very clearly shown in Fig. 1 which illustrates the results for the whole of the twenty years. With the exception of first calvers, the percentage age-composition of the animals drafted out of the herd is seen to be almost exactly the same as the percentage age-composition of the herd.

*Causes of wastage.*—As an introduction to the discussion of causes of wastage it is very essential to stress the fact that there is not a single record to indicate that any animal has been drafted out of the herd on account of unsatisfactory milk-yield. The closest examination of the data suggests that any low milk-yields have invariably been associated with, if not actually caused by, the ailments which are given as the reason for disposal.

As the terms used in Table 9 to describe the reasons for disposing of animals are those of ordinary farming parlance, it has been thought desirable to show the average price realized by most of the animals in each grade.

TABLE 9. *Causes of Wastage. Numbers and Prices*

| | | | | | | *Average prices 1919–32* | |
|---|---|---|---|---|---|---|---|
| *Years:* | *1912–17* | *1917–22* | *1922–7* | *1927–32* | *Total* | *Number* | *Aver. price* |
| | | | | | | | £ s. |
| Wasters | 14 | 27 | 21 | 19 | 81 | 49 | 3 15 |
| Bad doers | .. | 3 | 5 | 12 | 20 | 20 | 7 12 |
| Not stated | 17 | 17 | 2 | .. | 36 | 16 | 20 0 |
| | | | | | | 4 (fat) | 22 10 |
| Barreners or 'fat' | 6 | 6 | 17 | 29 | 58 | 43 (barren) | 13 7 |
| Udder troubles, milk fever, or calving | 3 | 3 | 1 | 8 | 15 | 12 | 4 12 |
| Lame or accident | .. | 2 | 2 | 3 | 7 | 5 | 5 4 |
| Old age | 2 | .. | 3 | 1 | 6 | 4 | 1 5 |
| | 42 | 58 | 51 | 72 | 223 | 153 | 9 4 |

The prices substantiate the general suitability of the descriptive terms. Occasionally T.B. was mentioned, Johne's disease rather more often, but it has been assumed that the less explicit, but the very significant, word 'waster', used by itself in most cases and supported by the average sale price of £3 15*s.* per beast, includes all such causes of disposal. The term 'bad doer' was introduced in 1919, and again the average price is a good indication of what is meant. Without doubt a majority of the cows described as 'barreners' were discarded on account of sterility, and with few exceptions these animals went out as 'grazers', no attempt being made to fatten them. Between 1919 and 1923 reasons for disposal were not always recorded, but the prices realized justified the inclusion of these animals in the barrener class. These explanations are given to introduce Table 10, which summarizes the relative incidence of the main causes of wastage.

TABLE 10. *Relative Incidence of Causes of Wastage*

| *Years:* | *1912–17* | *1917–22* | *1922–7* | *1927–32* | *All* |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| Wasters and bad doers | 33 | 52 | 51 | 43 | 45 |
| Barreners and fat | 55 | 40 | 37 | 40 | 42 |
| Udder, milk fever, and calving fatalities | 7 | 5 | 2 | 11 | 7 |
| Lame or accident | .. | 3 | 4 | 4 | 3 |
| Old age | 5 | .. | 6 | 2 | 3 |
| | 100 | 100 | 100 | 100 | 100 |

Thus in each of the four periods, 80–90 per cent. of the discards from the herd have been either wasters or barreners. The former have been in the highest proportions in the period 1917–22, when also, as was noted in Table 8, heifers had a low survival rate, and the age of drafts was below the average. A reduction in the proportion of wasters and bad doers takes place in succeeding periods, but these causes continue to be responsible for the main losses. All other causes of disposal, even when taken together, are comparatively insignificant. Udder defects, garget, milk fever, parturition fatalities, &c., have occasioned little loss although each of them has been recorded.

To compare these results with those from other investigations, it is necessary to eliminate such causes of disposal as 'low milk-yields', 'trade', 'tuberculin test', 'sundry', and 'miscellaneous', as these causes find no place in the herd under review. If this is done and comparison made with the summary of results from other centres, submitted by Wright at the meeting of the British Association 1932, it will be found that there is a marked agreement in the various records. Abortion, sterility, and tuberculosis are the chief causes of wastage.

Another serious aspect of the subject is brought to light by the examination of the incidence of the wastage in the various age-groups. The main facts are summarized by the curves in Fig. 2.

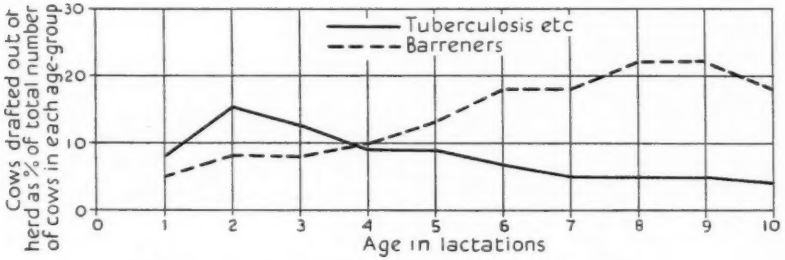


FIG. 2. Age incidence of cows drafted out of the herd.

Wasters and prospective wasters show their highest incidence, numerically and relatively, in second calvers. Of the total number of wasters, one-third was drawn from this age-group; of the total number of drafts from this group, two-thirds were wasters; whilst the same causes were responsible for the disposal of no less than 15 per cent. of all the animals in the group. Just lower than this wastage-peak is the incidence of this loss in the case of first and third calvers. From these three groups of young cows, three-quarters of all the wasters are drawn and always a high proportion of the group drafts (more than half), and 8–15 per cent. of the animals represented in the groups. It is of interest to note how resistant a number of the older cows have been to specific diseases which have proved fatal to younger animals.

Barreners, on the other hand, have been drawn in about equal numbers from each age-group so that, with declining numbers represented in the

drafts or in the group, the percentage of disposals increases with age. With young cows one-third of the drafts consisted of barreners, but this proportion rises to 50 per cent. of the fifth calvers, and higher still for old cows. Similarly, whilst 5–8 per cent. of the young cows in the herd are removed as barreners, the ratio reaches 20 per cent. with old animals.

A concise summary on the age incidence of wastage is given in Table 11.

TABLE 11. *Age Incidence of Wastage*

| *Cause* | *No.* | *Aver. age (in lactations)* | *% at various ages* | | | |
|---|---|---|---|---|---|---|
| | | | *1st–2nd calvers* | *3rd–4th calvers* | *5th–7th calvers* | *8th calvers* |
| Wasters and bad doers . | 100 | 2·8 | 57 | 27 | 13 | 3 |
| Barreners . . . | 94 | 4·3 | 34 | 23½ | 28½ | 14 |
| Others . . . . | 28 | 5·1 | 46 | .. | 23 | 31 |
| *All* . . . . | 222 | 3·7 | 44½ | 24 | 21½ | 10 |

It is apparent that youth and such ailments as T.B. and Johne's disease are very closely associated and that sterility has allowed the animals affected to give service on the average for a year and a half longer.

## PT. IV. *Abortion*

The mean age of first calving for the whole period was just under 3 years, and for the last few years has shown a tendency to decline. The distribution is shown in Fig. 3.

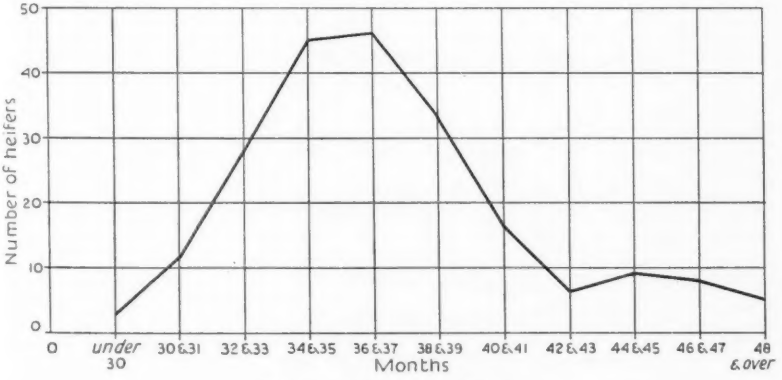


FIG. 3. Age of first calving.

Between the ages of 2½ and 3½ the curve is a normal one, but calvings after the latter age are very suggestive of abnormality, such as would be caused by an earlier premature parturition. Incidentally the lower average of first calvings in recent years is indicative of improvement in this respect.

In a previous section of this paper it was noted that 15 per cent. of all the calves in the herd were born prematurely or were dead at birth. These losses involved 152 lives resulting from 132 births (107 singles, 18 twins, 1 triplet and one each of 6 twins). Abortion is specifically stated to have been responsible for many dead calves, but 3 heifer calves born prematurely at eight months were reared. In other cases the term 'dead at birth' was used. Actual events, as they occurred year by year, were as follows:

TABLE 12. *Birth Casualties*

| | *1912–17* | *1917–22* | *1922–7* | *1927–32* | *Total* |
|---|---|---|---|---|---|
| Total births: | | | | | |
| Singles . . . | 172 | 186 | 235 | 282 | 875 |
| Twins . . . | 6 | 13 | 16 | 29 | 64 |
| Triplet . . . | 1 | .. | .. | .. | 1 |
| Total abortion and dead at birth (*a*) . . | 11 | 14½ | 52½ | 54 | 132 |
| 5-year periods % of all births . . . | 6·1 | 7·3 | 20·9 | 17·4 | 14 |

(*a*) One of twins has been reckoned as ½.

In the first decade, abortion occurred in six of the ten years, but in each of these years there were cases of either premature or still-born births. In the second decade, both abortion and dead calves are recorded every year. The degree of infection was at first insignificant, affecting from 1 to 3 per cent. of the births, whilst the proportion rose later on to 12 per cent. For the whole period of twenty years 7·7 per cent. of all births were premature.

These losses are further swollen by 6·4 per cent. due to still-born calves, so that in the final result no less than 14 per cent. of all the births were affected (or 15 per cent. of the calves, see p. 144). The incidence of abortion varied widely from year to year; the number of cases of 'dead at birth' varied to a much less extent.

In each of the five-year periods abortion and 'dead at birth' occurred more frequently in the case of multiple births than with singles, and for the whole period 7·1 per cent. of all the single births and 15·4 per cent. of the multiple births were abortions; the equivalent figures for 'dead at birth' were 5·1 per cent. in the case of singles, and 23·1 per cent. for twins.

A further analysis of the figures suggests that, with singles, abortion was about equally distributed between the sexes, whilst of the 45 single calves that were dead at birth, 14 were heifers and 31 were bulls. In the case of twins, the sexes appear to have been equally affected by the two causes of loss.

*Specific cases.*—Some interesting evidence with regard to the incidence of the disease was obtained by an examination of the data relating to 63 cases which occurred in the lactations of 39 cows. The majority of these abortions occurred in the ten years from 1922 to 1932.

TABLE 13. *Incidence of Abortion in Lactations*

0 = normal calving
1 = abortion

Cause of Disposal { W = waster; B = barrener; MF = milk fever }

| *Number of abortions* 1 | | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| 1 (B) | 0010 (W) | 11 (B) | 0111 (W) | 11011000 | 011111 (B) | |
| 1 (B) | 0010 (B) | 11 (B) | 01011 (B) | | | |
| 10 (W) | 0001 (W) | 11 (B) | 00111 (B) | | | |
| 10 (W) | 0001 (B) | 011 (B) | 100101 (B) | | | |
| 01 (B) | 00010 (W) | 0101 (W) | 0010011 (B) | | | |
| 01 (W) | 00100 (B) | 0100100 | | | | |
| 01 (W) | 00001 (W) | 0010001 | | | | |
| 01 (W) | 00001 (B) | | | | | |
| 010 (W) | 000010 (MF) | | | | | |
| 0100 (W) | 001000 | | | | | |
| 01000 (B) | 000001 (W) | | | | | |
| 010000 (W) | 00000001 (B) | | | | | |
| | 000000100 (W) | | | | | |
| No. of cows | 12 (25) 13 | 7 | 5 | 1 | 1 | 39 |
| No. of abortions | 25 | 14 | 15 | 4 | 5 | 63 |

In 25 cases abortion occurred but once in the life of the animal and 4 of these cases were with the first calf and 8 with the second calf. But clearly, one abortion in early life gave no security for the future, nor was freedom from abortion for a number of years necessarily a guarantee of immunity. The records also suggest a correlation between abortion and other causes of wastage. Thus 35 of the animals represented in the table have now been sold, 18 as barreners, 16 as wasters or bad doers, and one died from milk fever.

*Abortion and milk-yields.*—By an interesting coincidence it has been possible to compare the effect of abortion on the milk-yield in the subsequent lactation. In the course of recording the bulls used in the herd, the average milk-yields of a number of cows were determined. This was done by converting the lactation yields after the first, second, and third calves to a mature-yield basis and averaging these with other normal lactations. The mature yield in the first lactation was obtained by adding 30 per cent., in the second lactation by adding 20 per cent., and in the third lactation by adding 10 per cent. To other lactations no correction was made. All lactations were 315 days in length or less. On the other hand, abnormal yields resulted after each case of abortion (and in some cases before abortion). These were neglected for the purpose of bull-recording, but provided an opportunity to measure the reduction in milk-yield caused by premature births. Forty-seven such comparisons were made, and these are shown below in Table 14, subdivided to show the results after varying degrees of prematurity.

The general trend of these figures goes to prove that the earlier abortion occurs after conception the greater is the resulting loss in milk-yield, but the loss still remains as high as 26 per cent. even when the calf is carried for eight months.

*Intervals between calving.*—In practice two effects of abortion are

TABLE 14. *Reduced Milk-yields after Abortion*

| *Length of gestation* | *Number of abortions* | *Aver. normal mature milk-yield* | *Mature milk-yield after abortion* | *Decrease due to abortion* | *Decrease* % |
|---|---|---|---|---|---|
| 3–5 mths. | 4 | 980 | 490 | 490 | 50 |
| 6 ,, | 18 | 862 | 550 | 310 | 36 |
| 7 ,, | 14 | 960 | 660 | 300 | 31 |
| 8 ,, | 11 | 950 | 700 | 250 | 26 |
| *All* | 47 | 910 | 610 | 300 | 33 |

expected: sterility and delayed pregnancies. Evidence of the former has already been provided by these records. With regard to delayed pregnancies, the data show that the average interval between calvings in 358 normal cases was thirteen months, whilst the corresponding interval subsequent to abortions in 29 cases was 13·85 months. In 15 other cases, when one abortion followed another, the interval would have been 14·2 months if the second of these calves had been carried full time. Apparently, therefore, the delay in pregnancy subsequent to abortion averaged approximately one month in the above 44 examples.

### *The Life of the Dairy Cow*

The period of twenty years covered by this review is just long enough to make it possible to determine the actual average life of the majority of the cows in the herd. For this purpose all the animals in the herd from 1914 to 1928 were traced from the time of dropping their first calf to the dates of disposal. In this way it was found that 153 animals completed 484·5 cow-years in the herd or 3·2 years each. But this average omits 8 long-lived cows that were in the herd during part of the period, and were still alive in the spring of 1932, when they had contributed a total of 67 cow-years. To bring these animals into the reckoning, it might be assumed that they will each live for another year. The total number of cow-years for 161 animals then becomes 552, giving an average herd life per cow of three years and five months. As the average age of heifers at the time of first calving has been shown to have been three years, the average length of life of the cows in this herd has been approximately six and a half years.

### *Summary*

1. The subject-matter of this paper is a herd of dairy cows, numbering about thirty-six in the year 1912 and rising to over seventy in 1932, from which level quantities of milk have been sold daily and annually. Every animal, whether cow or calf, has been traced and the mass data analysed.

2. The standard of management of the herd is illustrated by (*a*) milk records, (*b*) evidence of remarkably effective control of matings, (*c*) the breeding technique including the use of proven sires, (*d*) the minute care taken to record events, and (*e*) the average life of the cows in the herd.

3. On the average, 30 calves or 15 heifer calves were required to produce between 9 and 10 dairy cows. The causes of wastage in calves and pre-herd heifers, in order of importance, were abortion and dead-at-birth,

wasters and bad doers, deaths, and twin to bulls. Fifteen per cent. of a total of 1,006 calves were born dead or died at birth, and the wastage in calves was much higher in multiple than in single births.

4. The average age of the cows in the herd and of cows drafted out of the herd over the whole period of twenty years was (in terms of calvings) 3·17 and 3·7 respectively. Wastage took place at the rate of 1 in 6½ in first calvers, 1 in 4 (approximately) in second to fifth calvers, this ratio getting narrower only very gradually to 3·5 with cows of 6 to 9 lactations and 2 at 10 lactations. With the exception of first calvers, the age-composition of cows drafted out corresponded very closely with that of cows retained in the herd.

5. The main causes of wastage in cows were wasters, bad doers, and barreners, all other causes being comparatively insignificant. The incidence of these causes of wastage is shown; for example, one-third of all the wasters and bad doers were drawn from second calvers, whilst there were comparatively few barreners in early life. The percentage of the animals in each age-group disposed of for these causes (shown graphically in Fig. 2, p. 148) were:

| *Age in lactations* | *1* | *2* | *3* | *4* | *5* | *6–7* | *8–9* | *10* |
|---|---|---|---|---|---|---|---|---|
| Wastage and bad doers . | 8 | 15 | 12½ | 9 | 9 | 6 | 5 | 4 |
| Barreners . . . | 5 | 8 | 8 | 10 | 13 | 18 | 22 | 18 |

In terms of calvings, the average age of wasters and bad doers was 2·8 and of barreners 4·3.

6. The incidence and losses occasioned by abortion have been measured in various ways. Thus:

(*a*) The average interval between 358 normal calvings was thirteen months compared with fourteen months subsequent to abortion (44 cases).

(*b*) Of a total of 940 births, 7·7 per cent. were abortions, and a further 6·4 per cent. were dead at birth.

(*c*) The incidence of abortion and dead at birth in singles and twins were: abortion 7·1 per cent. of single births, and 15·4 per cent. of the twins; dead at birth 5·1 per cent. of the singles, and 23·1 per cent. of the twins.

(*d*) The incidence of abortion rose from 5·2 per cent. in first calvers to 12·5 per cent. in second calvers, and remained at a high level in subsequent lactations.

(*e*) The reduction in milk-yield subsequent to abortion varied from 26 per cent. when the abortion occurred at the eighth month of gestation to 50 per cent. when it occurred at the third to the fifth month of gestation.

7. The incidence of wastage due to wasting diseases rose quickly to a maximum at the second lactation and then fell slowly, whereas the incidence of wastage due to sterility and abortion was lowest in early life and increased with age.

(*Received August 15, 1933*)

# INVESTIGATIONS OF THE MANURIAL EFFECTIVENESS OF AMMONIUM PHOSPHATE

## *Pt. I.* INTRODUCTORY AND HISTORICAL

A. H. LEWIS and KATHLEEN J. SINCLAIR
(*I.C.I. Agricultural Research Station, Jealott's Hill, Berks.*)

In recent years high-analysis or concentrated fertilizers, which contain appreciably higher percentages of plant-nutrients than the fertilizers now commonly used, have appeared on the market. Of the materials which are used as fertilizers, urea (46·62 per cent. N), potassium nitrate (46·58 per cent. $K_2O$; 13·85 per cent. N), ammonium nitrate, monammonium phosphate (12·17 per cent. N; 61·74 per cent. $P_2O_5$) and diammonium phosphate (21·21 per cent. N; 53·77 per cent. $P_2O_5$) can all be classed as concentrated. Mono- and di-potassium phosphates have as yet been little used in practice, probably owing to the high cost of manufacture. Concentrated fertilizers have an advantage over ordinary low-grade mixtures in reducing freight and handling charges very considerably. Since it is essential in agriculture, as in all other industries, to reduce production costs to a minimum, concentrated fertilizers will prove of great utility provided that they give increases in yield as good as those obtained with mixtures of low analysis.

Of the materials enumerated above, the ammonium phosphates have been most used up to the present, both as the basis of high-analysis complete (NPK) fertilizers and as NP fertilizers. The German concentrated fertilizers known as Nitrophoskas were among the earliest concentrated fertilizers placed on the market. The various grades of Nitrophoska are made by adding a mixture of diammonium phosphate and muriate of potash to fused ammonium nitrate, and they are all essentially mixtures of diammonium phosphate, ammonium chloride, and potassium nitrate [1].

Diammonium phosphate is also the basis of the German products Diammonphos and Leunaphos. Monammonium phosphate is manufactured in Great Britain, and is marketed in granular form, mixed with various amounts of ammonium sulphate, under the name 'NP' fertilizers in the home market and as Nicifos (or Amiciphos) overseas. Granular mixtures with various amounts of ammonium sulphate and potassium sulphate or chloride are known as 'C.C.F's' or, in some overseas markets, as Enpekay. Similar mixtures of monammonium phosphate and ammonium sulphate are made in the U.S.A. and marketed under the name Ammophos.

The aim of this series of papers is to compare the relative fertilizer effectiveness of concentrated fertilizers based on ammonium phosphates with that of ordinary mixtures. This paper is confined to a discussion of the theoretical advantages and disadvantages of ammonium phosphates, and to a survey of the literature dealing with results of experiments in which the effects of ammonium phosphates on growth and yield are compared with those of equivalent low-analysis mixtures.

*Advantages of ammonium phosphates.*—Apart from the question of bulk, one possible advantage of concentrated fertilizers containing ammonium phosphates over ordinary fertilizers is that the phosphate of ammonium phosphates may be more readily available to the plant than the phosphate of calcium phosphates. It has been argued by Cooper and Wilson [2] that this should be so, because the decomposition or discharge-potential of ammonium phosphate is lower than that of calcium phosphate, so that for the assimilation of the former the plant could utilize radiant energy of lower quality than that needed for the assimilation of the latter.

Greenhill and Page [3] report significant positive correlations between the N- and $P_2O_5$-contents of intensively treated pasture, and point out that this correlation may indicate that phosphate-uptake is in some way dependent on nitrogen-absorption or translocation, or vice versa. With the N and $P_2O_5$ chemically combined in ammonium phosphates, the uptake of N and $P_2O_5$ might be greater than when they are supplied in separate compounds.

It must be remembered, however, that the plant has to deal with the products of the reaction of the fertilizer with the soil, and with ammonium phosphates one final reaction-product is probably some form of calcium phosphate, except on very acid soils where aluminium and iron phosphates may be formed.

It is known that the presence of phosphate considerably increases the rate of nitrate-formation [4], and if the ammonia and phosphate are in intimate contact, as they are in ammonium phosphates, it is possible that nitrification would be more rapid than where the two are present in separate particles.

*Disadvantages of ammonium phosphates.*—Since the ammonium phosphates were introduced as fertilizers, much attention has been focused on possible dangers involved in their use under certain rather extreme climatic and soil conditions. Plasmolysis of the root-tissues may be the cause of the injury sometimes occurring when soluble fertilizers are used, but, as pointed out by Beaumont [5], the dangers due to this cause should be less with concentrated fertilizers than with low-analysis fertilizers furnishing the same amounts of plant-food. Beaumont [6] has, however, reported a reduction in the stand of sweet corn due to the use of concentrated fertilizers, but the injury was overcome by thoroughly incorporating the fertilizer with the soil. Skinner, Williams, and Mann [7] found a similar injury to cotton seedlings following the use of concentrated fertilizers on sandy soils. On the other hand, Allison [8] concluded from the results of a detailed study of Ammophos that monammonium phosphate behaved more or less in the same way as ammonium sulphate plus superphosphate even where injury to plant-growth occurred.

In producing concentrated fertilizers the aim is to eliminate, so far as possible, all unnecessary or 'filler' material. Although such elimination has the great economic advantage of reducing transport and handling charges, it may possibly be carried too far, since some of this apparently unwanted material may, in point of fact, be useful, especially under certain climatic and soil conditions. The absence of such elements as

manganese, copper, &c., traces of which are essential for plant-growth, is seldom likely to lead to difficulties, but the absence of calcium, and perhaps that of sulphur, both of which are present in considerable amounts in most low-analysis fertilizers, might more frequently be a disadvantage. Concentrated fertilizers containing ammonium sulphate may be expected to contain sufficient sulphur, but they usually contain little or no calcium.

Willis and Piland [9] have shown that on a sandy soil of low absorptive capacity diammonium phosphate, sown under the seed but not in contact with it, was injurious to the seedling-growth of cotton, and concluded that the free ammonia formed by hydrolysis of the diammonium phosphate was the most toxic component. No injury was noted with ammonium sulphate, chloride or nitrate, and the alkalinity (hydroxyl ions) of the diammonium phosphate did not appear to contribute to the result. The injury was reduced very considerably by calcium sulphate and calcium chloride, to a less extent by monocalcium phosphate, and very little by calcium carbonate. Monammonium phosphate was much less toxic than diammonium phosphate, but the addition of calcium sulphate reduced the injury more with the latter than with the former. The effect of monammonium phosphate in the presence of calcium carbonate is not stated. Willis and Piland suggest that whilst the beneficial effect of calcium sulphate was largely due to the formation of non-toxic ammonium sulphate and calcium carbonate, there was some indication that the physiological antagonism of calcium ions and ammonium ions was to a smaller extent responsible for the reduction in injury.[1] The lack of beneficial effect with calcium carbonate is attributed to the fact that although calcium tended to exert a beneficial effect, the concentration of ammonium carbonate was increased. It also seems clear from the results that the phosphate ion was moderately toxic, since the reduction in injury was much less with monocalcium phosphate than with calcium sulphate. Shive [10] found that di-acid phosphates were toxic to soya beans under certain conditions, but emphasized that the injury was due to a combination of factors including acidity. Willis and Piland (loc. cit.) point out that where the fertilizer is sown in a layer under the seed the extent of the injury would be expected to be greatest with tap-rooted crops.

It appears to the present writers that, whilst *ammonia* toxicity with diammonium phosphate[2] may occur on any sandy soil, the danger of ammonia toxicity with monammonium phosphate will be very much less, should occur only on very alkaline sandy soils, and should be no more marked than with other neutral or acid ammonium salts. Physiological toxicity of *ammonium ions*, however, may occur with any ammonium

[1] There appears to be no reason to doubt that the exclusion of calcium from fertilizers may, under certain conditions, result in 'physiological toxicity', due to monovalent cations, the effect of which is to increase abnormally the permeability of plant-cells. This increase in permeability is 'antagonized' by certain combinations of salts. Generally it is found that the greatest antagonism exists between mono- and di-valent cations.

[2] Willis and Piland point out that a M/10 solution of diammonium phosphate has a pH of 8, indicating an appreciable degree of hydrolysis, and that solid diammonium phosphate has an ammonia vapour pressure of 1·4 mm. at 80° C.

salt on soils deficient in calcium and of low absorptive capacity when calcium salt is not also added.

On acid, sandy soils, an increase in acidity (by exchange reaction) due to the application of monammonium phosphate will also increase any tendency for physiological toxicity of hydrogen ions. When mixtures of ammonium sulphate and superphosphate are applied, an even greater temporary increase in acidity would be expected, but superphosphate supplies a large amount of ionizable calcium, which probably antagonizes hydrogen-ion toxicity. Hence, it would appear that there might be little difference between mixtures containing monammonium phosphate and ordinary mixtures due to this cause.

The effect of ammonium salts in controlling the growth of weeds in lawns is attributed in part to the physiological toxicity of ammonium ions, the majority of dicotyledonous weeds appearing to be very susceptible, whilst high concentrations of ammonium ions in the soil do not appear to affect the monocotyledonous grasses [11]. Here, ammonium sulphate produced a very marked effect, whilst in Willis and Piland's experiments on cotton this material was not toxic. This confirms their conclusion that free-ammonia toxicity was the major cause of the injury in their experiments, and indicates that 'physiological toxicity' of ammonium ions was of minor importance. It also indicates that the extent of ammonium-ion toxicity with ammonium phosphates will vary considerably from crop to crop, e.g. no injury may occur with monocotyledons.

Another possible difference between concentrated fertilizers containing ammonium phosphate, and ordinary fertilizers containing some form of calcium phosphate, is that the phosphate of the former may penetrate farther into the soil than that of the latter.

Stephenson and Chapman [12] have shown that, as would be expected, texture and structure of soil influence the penetration of $P_2O_5$, and that the rate of application of $P_2O_5$ is also important. In a moderately compacted loam, free from $CaCO_3$ but somewhat alkaline, they showed that greater penetration of $P_2O_5$ occurred with triple superphosphate than with Ammophos containing its $P_2O_5$ as monammonium phosphate.

Waynick and Leavitt [13] applied moderately large dressings of Ammophos in solution to soils of different types, and showed that soil texture was important in influencing the penetration of $P_2O_5$. Even in an adobe (heavy) soil they found evidence of considerable penetration of the $P_2O_5$ of Ammophos.

Midgley [14] has also studied in some detail the penetration of the $P_2O_5$ of different phosphorus-carrying materials. The results of laboratory experiments clearly indicated the slower downward movement of the $P_2O_5$ of superphosphate compared with that of Ammophos and potassium and sodium phosphates. The results showed that the extent of the downward movement was less the greater the replacing power of the cation of the phosphatic salt. Midgley's results also indicated that certain manurial salts have a considerable influence on the movement of the $P_2O_5$ of superphosphate. Calcium hydroxide and ammonium and potassium sulphates reduced, whilst sodium nitrate markedly increased, the downward movement.

Although the possible difference in the penetration of phosphate into the soil may be in favour of ammonium phosphates under certain circumstances, it may be a disadvantage under heavy rainfall conditions, especially on light soils, where part of the phosphate of the ammonium phosphates might be removed from the root-zone of shallow-rooted crops.

*Experiments in Great Britain.*—The results of experiments in which ammonium phosphates were compared with equivalent mixtures of sulphate of ammonia and superphosphate are given in the Rothamsted Annual Reports. The results are summarized in the following table:

*Rothamsted Experiments*

| *Centre* | *Year* | *Crop* | *'C.C.F.'** | *Ordinary mixture* | *Standard error* |
|---|---|---|---|---|---|
| 1. Rothamsted . | 1927 | Swedes: roots, tons/acre | 15·19 | 14·99 | 0·22 |
| | | ,, tops, ,, ,, | 5·23 | 5·28 | 0·12 |
| 2. Woburn . | 1928 | Potatoes: tons/acre | 13·0 | 13·8 | 0·33 |
| 3. Tunstall . | 1931 | ,, ,, ,, | 12·3 | 11·91 | 0·286 |
| 4. Loughborough | 1931 | ,, ,, ,, | 8·71 | 8·26 | 0·221 |
| 5. St. Albans . | 1931 | Grass: dry matter, cwt./acre | 78·1 | 81·0 | 2·6 |
| 6. St. Albans† . | 1932 | Potatoes: tons/acre | 12·57 | 12·61 | 0·145 |

* Monammonium phosphate was used at Centres 1, 3, 4, 5, and 6, and diammonium phosphate at Centre 2. † Means for two equivalent rates of application.

None of the differences in yield between the concentrated fertilizer and the ordinary mixture is significant.

*Experiments in Germany and Denmark.*—A large number of trials comparing Nitrophoska with an equivalent mixture of ammonium sulphate, superphosphate, and potash salts on different crops, was conducted in Germany during 1927–9.

In 1927 Nitrophoska showed a slight superiority on cereals, which was attributed to a more even distribution of nutrients [15]. On potatoes and roots the differences in yield with Nitrophoska and the ordinary mixture were generally within the limits of experimental error [16]. The results on cereals and root-crops in 1928 were in most cases somewhat in favour of Nitrophoska [17]. A slightly lower efficiency of Nitrophoska on spring than on autumn cereals was found and was ascribed to summer dryness. The results of the 1929 trials were also slightly in favour of Nitrophoska [18]. Altogether ninety-nine trials were carried out by the German Agricultural Society on cereals and fifty-four trials on roots, and the results are considered by Nolte to be in favour of Nitrophoska.

A series of experiments carried out by Weigert and Fürst [19] on cereals, potatoes, and sugar-beet in Bavaria, confirms the results reported by Nolte. Engels [20] describes trials in 1928 on sugar-beet on a loam soil well supplied with lime, in which Nitrophoska compared favourably with equivalent mixtures. The results of fourteen experiments on cereals in Schwiebus showed no significant difference between the mean yields of grain and straw obtained from Nitrophoska and those from equivalent ordinary mixtures [21]. At the Rostock Experiment Station, Nitrophoska gave slightly higher yields of potatoes, swedes, and oats than equivalent ordinary mixtures [22]. Munter [23] concludes from the results of pot

and field experiments, conducted for one season only, that on strongly acid soils Nitrophoska, by reason of its physiologically acid character, cannot work efficiently, but that this is less true of Nitrophoska than of ammonium sulphate, and that the defect can be overcome by liming.

Trials on maize and carrots on different soils in Silesia, described by Werner [24], indicate that on sandy soils with small absorptive power the simultaneous application of Nitrophoska and large dressings of lime may lead to the production of ammonium carbonate with loss of nitrogen. In addition, there may be a direct toxic action of free ammonia on the plants. It would appear possible that the application of Nitrophoska or other fertilizers containing ammonium phosphates to highly calcareous soils might result in the production of ammonium carbonate (cf. pp. 155–6). Werner (loc. cit.) also gives data which indicate that the phosphoric acid in Nitrophoska is often more effective than that in superphosphate on good-bodied soils, although the latter form may have the advantage on sandy soils. This advantage of Nitrophoska over superphosphate on good-bodied soils is in keeping with the suggestion of Cooper and Wilson [2].

H. K. Olsen [25] concludes from 381 experiments in Denmark, that Nitrophoska gave better results than equivalent ordinary mixtures on acid-loving crops, including potatoes, oats, rye, grass, &c. F. Olsen [26] reports results of ten experiments laid down on grassland in Jutland, Denmark, in 1929 and 1930, in which Nitrophoska compared favourably with equivalent ordinary mixtures.

*Experiments in North America.*—Reports from Agricultural Experiment Stations in the *United States* on the fertilizing value of ammonium phosphates are somewhat conflicting. Stalling [27] reports failure of Nitrophoska and Ammophos on potatoes on fine sandy soils in Florida; sprouting and growth of the plants were retarded and the stand was poor.

On cotton at the Mississippi Agricultural Experiment Station [28] in 1927, Nitrophoska gave a rather lower yield than an equivalent ordinary mixture. Nitrophoska, however, gave promising results on grassland in trials at Massachusetts Agricultural Experiment Station [29] in 1928. In trials on potatoes at the Fredericton Experiment Station [30], New Brunswick, Canada, Nitrophoska compared favourably with an equivalent mixture.

Brown [31] reports the results of experiments on potatoes in Maine, Pennsylvania, New Jersey, New York, Virginia, and at Cornell, which show that Ammophos was on an average equal or slightly superior to equivalent ordinary mixtures. Ammophos gave, however, certain unsatisfactory results which were traced mainly to rainfall deficiency or to the light sandy character of the soil. In Virginia, on Norfolk sandy loam, all concentrated fertilizers gave poor results in 1926 and 1927, which were years of low rainfall, but were equal to the ordinary mixtures in 1928, a year of good rainfall [32]. In experiments extending over four years on Canfield silt loam at the Ohio Agricultural Experiment Station [33], Ammophos applied in the hill to maize gave increases practically identical with those obtained from equivalent mixtures of sodium nitrate and superphosphate. In a two-year test at this Station,

Ammophos used for spring top-dressing of wheat gave about the same increases as equivalent ordinary mixtures.

Skinner and Buie [34] report five-year experiments with cotton on Norfolk and Marlboro sandy loams in South Carolina, in which Ammophos gave about the same yield as equivalent ordinary mixtures. Ammophos was found to be rather less effective than an equivalent mixture in one-year tests on cotton, at the Mississippi Holly Springs Branch Station [35], at the Mississippi Raymond Branch Station [36], and at the Georgia Experiment Station on Cecil sandy loam [37]. Unfavourable results are also reported on tobacco on Tifton sandy loam at the Georgia Coastal Plain Station [38]; and on tobacco on Collington sandy loam in Maryland [39].

Shutt [40] summarizes results of experiments conducted with Ammophos in *Canada*. Ammophos was compared with ordinary mixtures on potatoes on light sandy loam at Charlottetown, and on clay loam at Fredericton. On both soils Ammophos compared favourably with equivalent ordinary mixtures. Ammophos was also tested on turnips on gravelly loam soil at Kentville, and gave about the same results as an equivalent mixture.

*Experiments in the Tropics.*—In a review of experiments with ammonium phosphate in *India*, Walker [41] refers to good results obtained with Ammophos on paddy in the Bombay Presidency on the stiff black soils of the North Thana district, on paddy in Mysore State and at the experiment stations at Nagercoil and Eraniel, Travancore. Hendry [42] described experiments on paddy in *Lower Burma*. Ammophos, Diammonphos and superphosphate plus ammonium sulphate gave the same increases in grain (96·8 per cent. for Diammonphos, 98·1 per cent. for Ammophos, and 98·1 per cent. for the mixture).

In experiments on rice at Labuduwa, *Ceylon*, in 1928–9, Ammophos and equivalent mixtures of ammonium sulphate and superphosphate gave increases in yield of 69 per cent. and 63 per cent. respectively over the control plots. Significant, though smaller, increases in favour of Ammophos were obtained on rice at Anuradhapura, Ceylon, in 1929 [43].

In experiments on sugar-cane at Pasoerean, *Java*, Ammophos gave similar results to an equivalent mixture of ammonium sulphate and double superphosphate [44]. Trials of Nitrophoska on young rubber and on trees of tapping age in Java, are reported by Ament [45], and by Vollema [46]. Instances of response to Nitrophoska are cited, but the experimental results are complicated by the variability of soil characters.

*Experiment in New Zealand.*—In an experiment on wheat at the Ashburton Experimental Farm, Canterbury district, New Zealand, in 1926–7, there was no significant difference between the yields obtained with Ammophos and an equivalent mixture of superphosphate and ammonium sulphate [47].

## *Summary and Conclusions*

The theoretical and practical advantages and disadvantages of concentrated fertilizers based on mon- and diammonium phosphates have been discussed. Apart from the economic advantages of reduced trans-

port and handling charges, the suggestion of Cooper and Wilson that the phosphate of ammonium phosphates is more available to the plant than that of calcium phosphate, appears to be supported by the results of some field experiments.

It is pointed out that the elimination of apparently unnecessary 'filler' material from fertilizers may possibly be carried too far since some of this 'filler' material may be necessary under certain soil conditions. Although the elimination of elements like manganese, copper, &c., is likely to lead to difficulties only in extremely few cases, the elimination of calcium and perhaps sulphur might more frequently be disadvantageous.

Toxicity due to ammonia or ammonium carbonate may occur with diammonium phosphate on sandy soils. The danger of ammonia toxicity with monammonium phosphate appears to be remote except on very alkaline sandy soils. This type of toxicity is counteracted by soluble calcium salts.

Physiological toxicity of ammonium ions may occur with both the mono- and di-salts on sandy soils deficient in calcium. Calcium salts antagonize this type of toxicity, which can, of course, occur with monovalent cations other than ammonium ions. On acid, poorly buffered soils the increased hydrogen-ion concentration with monammonium phosphate may cause some injury, but the danger is possibly no greater than with ordinary mixtures containing ammonium sulphate and superphosphate. Phosphate toxicity might also occur with ammonium phosphates.

The extent of injury due to ammonia or ammonium-ion toxicity will be less, of course, where the fertilizer is broadcast than where it is sown in the drills, and will vary from crop to crop; monocotyledons appear to be more tolerant than dicotyledons. Where the fertilizer is sown in the drills beneath the seed, the injury should be greatest with tap-rooted plants.

There is some evidence that the $P_2O_5$ of ammonium phosphates may penetrate farther into the soil. This might give ammonium phosphates an advantage over ordinary mixtures containing calcium phosphates with deep-rooted crops, but might be a disadvantage with shallow-rooted crops. This difference would be most marked on sandy soils under high rainfall conditions.

The literature giving the results of experiments to compare the fertilizing properties of ammonium phosphates with equivalent ordinary mixtures is reviewed. The results of a large number of experiments conducted in many parts of the world show that, in general, concentrated fertilizers based on ammonium phosphates give the same results as equivalent ordinary mixtures; some of the results are in favour of ammonium phosphates and others are in favour of the ordinary mixtures; except in a few extreme cases, the difference in yield was small. Plentiful supply of moisture and good-bodied soils appear to favour ammonium phosphates.

Since the survey of the literature given above indicates possible differences in effectiveness between ordinary mixtures and concentrated fertilizers based on ammonium phosphates under different climatic and soil conditions, a number of experiments to compare these two fertilizers under a wide range of climatic and soil conditions was undertaken in the British Isles; these are to be described in the succeeding paper.

The authors' thanks are due to Imperial Chemical Industries, Limited, for permission to publish this paper.

## REFERENCES

1. A. MITTASCH, Z. angew. Chem., 1928, **41**, 18.
2. H. P. COOPER and J. K. WILSON, Soil Sci., 1930, **30**, 421–30.
3. A. W. GREENHILL and H. J. PAGE, J. Agric. Sci., 1931, **21**, 220–32.
4. J. A. PRESCOTT and G. R. PRYOR, ibid., 1930, **20**, 517–31.
5. A. B. BEAUMONT, Better Crops, 1927, **7**, 12.
6. —— Amer. Fert., 1925, **62**, 23–4.
7. J. J. SKINNER, C. B. WILLIAMS, and H. B. MANN, North Carolina Agric. Expt. Stat. Bull. 266.
8. F. E. ALLISON, Soil Sci., 1918, **5**, 1–81.
9. L. G. WILLIS and J. R. PILAND, ibid., 1931, **31**, 5–24.
10. J. W. SHIVE, ibid., 1918, **5**, 87–122.
11. G. E. BLACKMAN, Ann. Appl. Biol., 1932, **19**, 204–20.
12. R. E. STEPHENSON and H. D. CHAPMAN, J. Amer. Soc. Agron., 1931, **23**, 759–70.
13. D. D. WAYNICK and F. H. LEAVITT, Calif. Citrograph, 1930, **15**, 152.
14. A. R. MIDGLEY, J. Amer. Soc. Agron., 1931, **23**, 788–99.
15. O. NOLTE, Mitt. D.L.G., 1927, **42**, 1130–5.
16. O. NOLTE and M. RAUTERBERG, ibid., 1928, **43**, 317–18.
17. O. NOLTE and H. MUNZBERG, ibid., 1929, **44**, 62–5.
18. H. MUNZBERG, ibid., 1929, **44**, 106–8.
19. J. WEIGERT and F. FÜRST, Praktische Blätter für Pflanzenbau und Pflanzenschutz, 1928, **5**, 299–308.
20. O. ENGELS, Z. Pflanzenernährung, 1929, **8B**, 561–8.
21. E. HOFFMANN, Fort. Landw., 1930, **5**, 397–8.
22. F. HONCAMP and H. WIESSMANN, Z. Pflanz., 1930, **9B**, 361–3.
23. F. MUNTER, Deut. Landw. Presse, 1927, **54**, 715–17.
24. H. WERNER, Z. Pflanz., 1930, **9B**, 339–59.
25. H. K. OLSEN, ibid., 1931, **10B**, 349–50, from Pflanzenbauausschuss für Fynen, Odense, Andelsbogtrykkeri, 1931.
26. F. OLSEN, Beretning om Virksomheden i Foreningen af Tydske landboforeningers Graesmarkssektion, 1930. Skanderborg Amtsbogtrykkeri, Holger C. Brix, 1931.
27. J. H. STALLING, Soil Sci., 1928, **26**, 351–62.
28. C. B. ANDERS and W. W. HALL, Mississippi Agric. Expt. Stat. Bull. 250, 1928.
29. Massachusetts Agric. Expt. Stat. Contribution No. 91, 1928.
30. Report of the Superintendent, Fredericton Experiment Station, for 1929, pp. 45–6.
31. B. E. BROWN and F. V. OWEN, Maine Agric. Expt. Stat. Bull. 350 (1929), and 354 (1930).
32. B. E. BROWN, Proc. Potato Assoc. Amer., 1928, 205–22.
33. Ohio Agric. Expt. Stat. Spec. Circ. 27, 1930, pp. 41, 43.
34. J. J. SKINNER and T. S. BUIE, South Carolina Agric. Expt. Stat. Bull. 227, 1926.
35. C. T. AMES and O. B. CASANOVA, Mississippi Agric. Expt. Stat. Bull. 272, 1929.
36. H. F. WALLACE and J. L. COOLEY, ibid., 271, 1929.
37. R. F. BLEDSOE, Georgia Agric. Expt. Stat. Bull. 152, 1929.
38. S. A. STARR, Georgia Coastal Plain Expt. Stat. Bull. 11, 1929.
39. W. W. GARNER and J. E. MCMURTREY, Agric. Res., 1930, **40**, 145–68.
40. F. T. SHUTT, Rept. of the Dominion Chemist, Canada Dept. of Agriculture for year ending March 31, 1927, pp. 9–11.
41. J. E. WALKER, Agriculture and Livestock in India, 1931, **1**, 159–67.
42. D. HENDRY, Agric. J. India, 1930, **25**, 126–37.
43. L. LORD, Trop. Agriculturist, 1929, **73**, 67–73.
44. G. BOOBERG, Archief Suikerind., 1929, **37**, 358–65.
45. C. C. AMENT, Archief voor de Rubbercultuur, 1931, **15**, 345–81.
46. J. S. VOLLEMA, ibid., 1931, **15**, 481–574.
47. A. W. HUDSON, New Zealand J. Agric., 1927, **35**, 251–7.

(*Received February 17, 1934*)

# THE RECLAMATION OF MOORLAND

W. G. OGG and IAN M. ROBERTSON
(*Macaulay Institute for Soil Research, Aberdeen*)

PEAT-FORMATION occurs under conditions in which the decomposition of organic matter is retarded or prevented. Although it is associated with humid conditions of the land-surface it is not confined to cold and wet climates. Even in the tropics peat occurs, but the most favourable conditions for its formation are to be found in the temperate zones. The decomposition of plant-remains is due mainly to the action of micro-organisms, and factors which prevent this action favour peat-formation; excessive moisture is the commonest, and associated with this is the exclusion of air. Other factors are high acidity and the shortage or absence of nutrients necessary for micro-organisms. Peat-formation tends to occur where the land-surface is flat, or in poorly drained hollows, but it is not confined to such conditions, and is found also on comparatively steep slopes where the climate is sufficiently humid. Since the plants from which peats form vary greatly on account of differences in soil, water, and climatic conditions generally, the composition of the resultant peats varies widely. These differences occur not only in different locations, but may be found in different layers of peat in one spot, for example, when the gradual accumulation of plant-remains raises the surface above the level of the surrounding water, the conditions of growth alter, and a new plant-community of different type may invade the area. This vegetation in turn forms a layer of peat which may differ entirely from that formed below.

It has been customary in all countries to recognize at least two main groups of peat-land corresponding in a general way to a difference in richness in plant-nutrients, and especially in lime. In Germany, all peat-land is included under the general term *Moor*, and this is subdivided into *Niederungsmoor* (rich in bases), *Hochmoor* (poor in bases), and an intermediate form known as *Übergangsmoor*. In Sweden, the general term for peat-land is *Myr*, and this is subdivided into *Kärr* and *Mosse*, corresponding broadly to the German *Niederungsmoor* and *Hochmoor*. Some confusion has arisen regarding the English equivalents of these terms. 'Fenland' and 'carr' correspond to *Niederungsmoor* and *Kärr*, whilst 'moor' has usually been taken to mean *Hochmoor* or *Mosse*. It would probably be more satisfactory to apply the term 'moorland' in English to all peat-land, and to use the old Scottish term 'moss' to cover the German *Hochmoor* and the Swedish *Mosse*.

*Fen and carr.*—These types occur where drainage water rich in plant-nutrients collects in hollows, and supports such plants as reeds (*Phragmites*) and sedges (*Carex*). These plants first invade the edges and shallower parts, and may gradually spread over the whole area, filling it up to the water-level with a peat comparatively rich in plant-foods. Various types are recognized, on the basis of the dominant plant which occurs, e.g. *Carex*, *Phragmites*, *Hypnum*, &c. Where the plant-

association consists largely of trees and shrubs, the term 'carr' is applied. Both fen and carr occur extensively in East Anglia, and to a less extent in certain other parts of Britain.

*Moss.*—The water associated with the formation of peat-mosses is usually rain-water, or ground-water very poor in bases, and the vegetation is composed mainly of such plants as mosses (e.g. *Sphagnum* and *Rhacomitrium*), coarse grasses (e.g. *Eriophorum*, *Scirpus*, *Nardus*), heather (*Calluna*), and heath (*Erica*), &c. The peat formed from these plants has a low mineral-content, and is usually intensely acid in reaction.

Various types of peat-mosses have been recognized, but it is sufficient here to mention two. One group is characterized by a convex surface; hence the German term *Hochmoor*, and Swedish *Högmosse*. It occurs in flat, or nearly flat areas, and various species of sphagnum are usually the chief constituents. The peat is often fibrous to a considerable depth. The term 'highmoor' commonly applied in English is rather misleading, as it may convey the impression that such mosses occur only at high altitudes, and in place of it 'raised moss' is suggested.

Another group which is associated with oceanic conditions of climate may be regarded as the other extreme. In most parts of Scotland the dominant plant in this group is *Scirpus*, and the peat is usually structureless. This type of peat is not confined to flat ground, but is found also on steep slopes; provisionally, it might be termed 'creeping moss'.

*Composition of peats.*—Since the formation of peat is due to the accumulation of plant-remains, it follows that a pure peat is mainly organic, although there is a small amount of mineral matter derived from the plants which form the peat. Besides the true peats, there are many peaty soils which contain varying amounts of mineral soil.

In its wet condition, peat may contain 95 per cent. of water, and even on well-drained peat-land the percentage of water amounts to about 85 per cent. The high content of water and the low content of mineral matter are features in which peat-soils differ fundamentally from mineral soils.

There is considerable variation in the composition of the organic matter in peats, but the usual range for the principal constituents is as follows: carbon 56–60, hydrogen 5–6, oxygen 34–6, and nitrogen 1–4 per cent. Comparatively little is known about the chemical constitution of the complex compounds in which the organic matter occurs, but it is well established that many of them are colloidal; and this has a very important bearing on drainage and other problems. The colloidal material renders certain peats very difficult to drain, and on the other hand it renders much of the water present unavailable to plants. Again, much of the small supply of phosphoric acid in acid peat-soils is unavailable to plants, because it is bound up in the colloidal material.

The form in which the nitrogen occurs in raw peats varies a great deal, but most of it is unavailable until biological and chemical processes are set up, which bring about the decomposition of the complex organic compounds.

The so-called humic and other acids which result from the humification of plant-remains give rise to an acid reaction unless there is sufficient

base present to neutralize them. Where this acidity is extreme it is very detrimental to the growth of agricultural plants. Not only is the direct action of the organic acids harmful, but they increase acidity by the decomposition of mineral salts added in the form of fertilizers.

In early work on peat-cultivation, when dung was the principal manure used, the free acid produced in this way was not sufficient to be particularly detrimental, but in modern practice, where large amounts of artificial manures are added, the amount of free acids formed from neutral salts may be considerable. It is important, therefore, to add sufficient lime to counteract this effect.

The inorganic substances which occur in peats vary greatly, and their amount and composition depend on the conditions under which the peat is formed. Where the ground-water is rich in plant-nutrients, the percentage of mineral matter in the resultant peat (e.g. fen-peat) is much higher than where the ground-water has a low content of bases. This has a very important bearing on the natural fertility of peat-land, and has led to the fen types, which are so much richer, being cultivated far more extensively than the moss types.

A comparison of a fen type with two moss types will serve to bring out the difference:

*Chemical Composition of Fen and Moss Peats*

(*Calculated on dry basis*)

| | *Nitrogen* | *Phosphoric acid* | *Potash* | *Lime* |
|---|---|---|---|---|
| Fen type (sedge peat) . . | 2·5 | 0·25 | 0·1 | 3·0 |
| Moss type (sphagnum peat) . | 1·2 | 0·05 | 0·05 | 0·3 |
| Moss type (scirpus peat) . . | 1·5 | 0·1 | 0·1 | 0·4 |

These figures show that the fen type is much richer in nitrogen, phosphoric acid, and potash than the moss types; and in lime the difference is particularly marked.

*Biological properties.*—On account of their water-logged condition (at any rate at certain times of the year), and consequent lack of aeration, there is little or no bacterial activity in peats under natural conditions, and in the moss types this unfavourable condition for bacterial life is accentuated by scarcity of nutrients and by high acidity. Drainage, cultivation, and liming bring about a great increase in bacterial activity, and this is supplemented by the application of farmyard manure. The increased bacterial activity, however, is more or less confined to the surface-layer, the material below the depth of cultivation differing very little from that of uncultivated land. Heavy liming tends to stimulate the activity of denitrifying organisms, and for this and other reasons should be avoided. Nodule bacteria are often absent in uncultivated peats of the moss types, and on freshly reclaimed land it is generally advisable to inoculate seeds of legumes before sowing. After bacterial activity is well established, humification of the peat proceeds, and conditions for the growth of agricultural crops become more satisfactory.

In dealing with the reclamation of moorland, distinction is drawn

between the treatment of fen and moss types. The main differences lie in the drainage system, the amounts of lime and manures required and in the crops to be grown. In the description of reclamation which follows, attention is confined to the moss types.

*Reclamation and cultivation of peat-mosses.*—From very early times, attempts have been made to utilize the vast areas of moorland in countries such as Britain, Holland, Germany, and Sweden. The fact that peat formed a cheap and efficient fuel was early realized, but it was not until fairly recent times that records of the cultivation of moorland have been found. Cultivation, or rather cropping, of the natural herbage, was restricted to the drier parts, but soon it was seen that the growth of peat could be stopped by the removal of the surplus water, and the first step in the production of a useful vegetation was to establish some sort of drainage system.

The other great difficulty which presented itself to the early workers was the introduction of plant-foods to the drained peat-land. The analyses already given show that the peat-mosses are very deficient in plant-nutrients, so that they form very poor soils unless this deficiency is overcome. By the older methods, paring and burning, treatment with dung, composts, lime, clay, soil, &c., were used to enrich the moss soils, but these have been replaced in modern practice by the addition of artificial fertilizers.

*Paring and burning* ('Brandkultur').—The practice of paring and burning was one of the earliest methods of moorland cultivation, and was known in Holland in the sixteenth century. It consisted of cutting from the surface a thin paring of peat, which was then gathered into heaps and burned when dry. After the ashes had been scattered over the surface, the land was sown with buckwheat, or in Scotland with bere or oats. Satisfactory yields could not be maintained unless the burning was repeated every three or four years, and this soon removed shallow peat-deposits, exposing in many cases a rock outcrop, or a shallow mineral soil. In addition, repeated burning left behind an unsuitable corky soil, and also made it impossible to use any other than a very simple system of open drains. The result was that the method fell into disuse in this country about the end of the eighteenth century, but continued to be used on the Continent until much later.

'Fehnkultur'.—Another method of moorland-cultivation, which originated in Holland probably before the sixteenth century, is known as *Fehnkultur*, and was connected with the cutting of fuel-peat from the deeper layers of the peat-land. The undecomposed upper layers of the peat, which were quite unsuitable for fuel, were cut off and thrown forward, exposing the black well-decomposed fuel-peat below. This was cut, dried, and then transported by boat to the towns. Usually a load of town refuse was taken back and applied to the rejected top layers, which were then cultivated with or without the addition of sand.

*Early Scottish work.*—In Scotland the early workers recognized that in reclaiming peat-land the best procedure was to drain the land, either by means of an open or covered drainage system; to add lime to reduce the natural acidity of the peat; and then to supply plant-foods in the

form of dung, compost, or mineral soil. Much reclamation work on these lines was carried out in the beginning of the nineteenth century, and it is worthy of note that the scheme adopted differed from modern continental practice only in the use of artificial fertilizers and of specially designed machinery. It would appear that the Scottish work on moorland reclamation of a century ago was in advance of the continental, but since that time little or no advance has been made in this country. Recently, however, modern continental methods have been tried on deep peat at the Macaulay Demonstration Farm in Lewis.

*Modern reclamation methods.*—The modern processes associated with moorland cultivation may be grouped under drainage, liming, manuring, cultivation, and cropping.

*Drainage.*—The control of the water-level by means of correct drainage is one of the first essentials. In its natural state, peat can hold as much as 95 per cent. of water, which must be reduced to about 85 per cent. in order to produce optimum moisture conditions for plant-growth. If drainage is carried too far, symptoms of drought and starvation appear, and in addition, great difficulty is often experienced in rewetting the light granular soil which results after the drying out of a peat soil. The colloidal nature of peat makes it particularly retentive of moisture, and up to about 60 per cent. can be present in a combined form, and be 'unavailable' to plants. It follows, therefore, that attention must be given to the construction of a suitable drainage system by means of which the water-level can be controlled to give an adequate water-supply to the growing plants during late spring and summer, and a maximum of drainage during the winter months. In districts of low rainfall, the needs of the crop often make it necessary to hold up the water within an area by means of sluices in the main drains. The drainage system most commonly used where large areas are to be reclaimed consists of a series of parallel collecting drains (usually left open), 3 ft. broad and $4\frac{1}{2}$ ft. deep, emptying directly into a main ditch or stream at intervals of 250–300 yards. The strips of land between the collecting ditches are drained by means of covered subsidiary drains, 20 yards apart, which run from the centre of each strip into the collecting drains. The approximate dimensions of the trenches that are prepared for the subsidiary drains are: average depth 4 ft.; breadth 2 ft. 6 in. at the surface, sloping to 1 ft. 3 in. at the bottom; length 125–50 yards, and fall 0·25 per cent. The dimensions and distances given above are averages for areas having an average rainfall of 25–32 in. In extremely wet districts the subsidiary drains may have to be set closer together.

The position of the main ditch, or leader, is usually determined by the topography of the land-surface. In most moorland areas natural water-courses are found which can be converted to an efficient leader by suitable widening and deepening. The depth is determined by the length and fall of the side drain. The sides of the leader should be sloped to the water-level, the angle of the slope depending on the character of the peat.

There are several details of practical importance to be observed in the installation of a closed drainage system. After the drain-trenches have

been cut, and the surface-water removed from the area, a shrinkage of the peat and consequent lowering of the surface-level usually take place, and may proceed for a considerable period. The nature of the peat, its depth, and the type and depth of the drains, all have an effect on the shrinkage, and determine to what extent it will proceed. It often happens that many kinds of peat occur within a comparatively small area, so that differential shrinkage may take place and cause both the sole of a drain and the surface to become uneven. It is therefore advisable to allow the trenches to remain open until most of the shrinkage has taken place, and then to clean out the bottom to the correct depth before laying the drains and filling in. To prevent displacement of box- or tile-drains in the soft peat, a layer of heather or similar material should be introduced into the bottom of the trench.

When cutting the drain-trenches, the subsidiary drains should not be run directly into the collecting ditches, but should be stopped some feet away, leaving a bank of peat between. A hole should then be cut through the bank into the collecting drain, on a level with the sole of the subsidiary drain. In this way the walls of the former remain unbroken. The laying of a closed drain should proceed from the mouth backwards, so that the proper fall can be given. In addition, the water pressed from the sides of the trenches during the work of laying the drain will be carried off by the drain, leaving a dry sole in front of the workmen.

*Types of drains.*—(*a*) *Turf-drains.* Turf-drains were used by the early workers in peat-land reclamation, and consisted of an approximately square channel built with dry peat or turf. A modification used in a firm peat-deposit was constructed by cutting a small trench in the sole of the drain, and covering it with peat or turf.

(*b*) *Faggot-drains.* Faggot-drains consist of bundles of brushwood about 10 in. in diameter. The ends of the bundles are allowed to overlap, and are then bound together to form a continuous structure the length of the drain trench. Turves or heather should be used as bedding and covering for the faggots. Pole-drains are similar to the above in construction, only long straight stems are used instead of brushwood. Faggot-drains require a greater fall than box- or tile-drains.

(*c*) *Box-drains.* In their simplest form box-drains consist of 'backs' (obtained during the dressing of logs), nailed together to form a box about 4 in. square. Sufficient space should be left between the top and sides for water to enter the drain. Another form is constructed of planks $\frac{1}{2}$ in. or $\frac{3}{4}$ in. thick, and 4 in. broad, nailed together to form one continuous box the whole length of the drain. The top is either raised slightly on small wooden strips, or provided with slots at suitable intervals to allow for percolation of the drainage water. A more elaborate type with the sides countersunk into the bottom is sometimes used, and its main advantage lies in the fact that these drains can remain in position without nails, an important point in acid peat where metal nails are quickly destroyed. Box-drains of triangular cross-section are also used.

(*d*) *Tile-drains.* Considerable difficulty is often experienced in the laying of tile-drains on peat-land, and displacement of the pipes in a badly laid system is almost sure to follow the passage of farm machinery

over the land-surface. If a little care is taken in laying the drains, however, tiles can be made to provide an efficient and cheap system, e.g. the tiles can be laid on boards; but a bed of heather or similar material has been found more satisfactory, and is cheaper.

The procedure is to fill the bottom of the trench with 6–8 in. of heather, which is pressed down evenly. A piece of iron tubing is next slipped through a convenient number of drain-pipes, and lowered on to the heather. After a good covering of heather has been placed on top, the trench is partly filled in and tramped hard. The iron tube is then removed, and the process repeated up the length of the drain. The heather, which may be replaced by brushwood, straw, reeds, &c., acts as a filter and a suitable bedding material.

In countries where timber is plentiful, wooden box-drains are usually employed, but where wood is scarce tile-drains may be cheaper and are equally efficient if properly laid.

*Liming.*—We have seen that the peat-mosses are very deficient in mineral matter, and contain a large proportion of organic acids, which are harmful to plants and bacterial life, and also cause the decomposition of certain manure salts (neutral salt decomposition) producing the mineral acids from which the salts were formed. The addition of the correct amount of lime as ground lime, hydrate, limestone, waste lime, marl, or shell-sand, brings about a reduction of the natural acidity and provides a medium suitable for both plants and bacteria. It has been noted that peat under natural conditions contains little or no bacterial life. After liming, however, and especially if this is supplemented by an application of dung, a great increase in the number and activity of bacteria is observed. In particular, the production of ammonia is increased, but the other processes brought about by soil-bacteria, e.g. nitrification and denitrification, are also stimulated. Optimum conditions for the nitrifying bacteria are not obtained until the acidity has been neutralized completely, but before this point is reached the very harmful effects of the denitrifying organisms are very apparent. Although therefore it is absolutely necessary to reduce the acidity of a peat-soil, care must be taken not to over-lime.

The amount of lime to be applied varies with the crop to be grown. Cropped land, for instance, requires much less than hay- and pasture-land, but usually dressings of lime (CaO) at the rate of 20–25 cwt. per acre to the former, and 35–40 cwt. per acre to the latter, are satisfactory. Generally, a newly reclaimed area is cropped for a year or two before it is sown down in permanent grass, and in such cases the lighter dressing should be given at first, and supplemented by a second dressing before the grass is sown.

To obtain the maximum effect from lime it should be very finely ground, and distributed uniformly throughout the area. Before ploughing, a portion of the lime (usually about one-half) is applied and worked in with disk-harrows, and after ploughing the remainder is spread on the surface and worked in as before. After a good intermixing with the soil is obtained, the effect of the lime will persist for many years, especially if basic slag or ground mineral phosphate is used as phosphatic manure.

*Manuring.*—The amounts of phosphoric acid, potash, and available nitrogen in peat-soils are very low, and heavy dressings of artificial fertilizers must be given in the first few years until a reserve is built up. Phosphoric acid is usually applied in basic slag or ground mineral phosphate, at the rate of 130–50 lb. per acre ($P_2O_5$), representing 7–9 cwt. per acre of basic slag and 3–4 cwt. per acre of ground mineral phosphate respectively. Unless there is a large reserve of lime, superphosphate is considered undesirable on account of the formation of sulphuric acid. Phosphatic manures should be applied in autumn or early spring in order that the humic acid may render soluble the 'unavailable' calcium phosphate, particularly when ground mineral phosphate is used.

Potash is best given in potash manure salts, at the rate of 150–70 lb. per acre ($K_2O$), representing 4½–5 cwt. potash manure salts. In the first year or two, at least part of the potash should be given in autumn to obtain a thorough mixing with the newly reclaimed soil, but in subsequent years it is best applied in spring. Potash is much less firmly held than phosphate, and late application minimizes losses due to leaching.

After the initial heavy dressings of phosphate and potash, the amounts to be added depend on the yield of crop removed, the crop to be grown, and the losses due to leaching. Generally, the recommendations are as follows: 50–60 lb. per acre phosphoric acid ($P_2O_5$), and 80–90 lb. per acre potash ($K_2O$) for cropped land, and 30 lb. per acre phosphoric acid and 60 lb. per acre potash for pasture.

Although peat-soils have a fairly high nitrogen-content, very little of this element is present in an available form, especially in freshly reclaimed land. Until the effects of drainage, cultivation, liming, and bacterial activity have time to come into play, it is advisable to use artificial nitrogenous fertilizers at the rate of 40–50 lb. per acre nitrogen for cereals and slightly more for roots. In acid peat-soils the nitrogen is best added in the physiologically alkaline manures such as saltpetre and nitrochalk, but, if sufficient lime be present, sulphate of ammonia may be used. With most crops the nitrogen should be applied at the time of sowing, but with potatoes the application may be delayed for a week or two after planting. Leguminous crops do not require nitrogenous fertilizers provided nodule-bacteria are present in sufficient quantity, and in this connexion it is usually found profitable to inoculate clover seeds before sowing.

Farmyard manure and composts are of great value on peat-land, and introduce both plant-foods and bacteria to the soil; the latter are of particular importance in a freshly reclaimed peat-soil, which is usually almost sterile. Green manuring with a leguminous crop also provides a means of increasing the amount of available nitrogen in the soil.

*Cultivation.*—The production of a good tilth in a freshly reclaimed area of peat-land is usually far from easy. The natural vegetation forms a tough and matted surface-layer in which the peat is held together by the roots of the growing plants. Often small trees and shrubs increase the difficulties of the cultivation operations. Before cultivation is commenced, the surface vegetation should be burned off when sufficiently dry, and in some cases several inches of the surface layer of tough peat

can with advantage be pared off, allowed to dry, and burned. A good tilth is rarely secured until cultivation has been carried out for a number of years, and the effects of drainage and liming have come into play. Accordingly, potatoes or oats are grown in the first few years until a sufficiently fine seed-bed is obtained for the finer grass and clover seeds.

The actual cultivation operations are usually conducted by mechanically driven implements specially designed for work on peat-land. If ploughing is undertaken, the surface should be broken with sharp cutting harrows, otherwise long continuous furrows of unbroken peat will result.

A more efficient and speedy method of cultivation is to use a series of steel knives attached to a rapidly revolving drum. This machine is drawn by a tractor, and can be raised or lowered to vary the depth of cultivation. Even with a very tough fibrous peat a good seed-bed can be obtained after two operations. At first, the cultivation is carried out to a depth of 3 or 4 inches, and afterwards the area is crossed with the cultivator working to its maximum depth. Lime and manures can also be worked in with this machine. The tilth obtained is so good that an area can be sown down in grass at once, without any previous cropping. All machinery should be of the caterpillar type or should be fitted with broad wheels to prevent sinking.

The cultivation processes described above produce a very light porous soil through which rain-water quickly passes, carrying down the plant-nutrients. In dry weather the surface-layer soon loses its moisture, and is too loose to have much capillary connexion with the subsoil. Rolling with a heavy roller firms up the soil, and helps greatly to keep moisture in the surface-layer. For ease of working on soft peat-land, a roller should have a fairly large diameter. Cement- or sand-filled rollers of small diameter often become bogged and are difficult to remove; to overcome this difficulty water-filled rollers of large diameter have been constructed for use with tractors. The approximate dimensions of a suitable roller are: length $5\frac{1}{2}$ ft. and diameter 4 ft. The empty shell weighs about $1\frac{1}{4}$ tons, and holds up to 2 tons of water. Generally a weight of 6 cwt. per foot of working surface is required, but where soft peat is encountered, the weight of the roller can be reduced by removing some of the water.

Peat-land cultivation can be carried out with ordinary farm implements, but is of necessity slower than with the machinery specially designed for moorland work. On soft land it is usually necessary to provide horses with broad wooden shoes, which are attached to the hooves by broad metal bands.

*Cropping.*—On freshly reclaimed peat-land the most suitable crops are oats, rye, and potatoes. The cereals present least trouble in the wet lumpy soil which usually characterizes a newly cultivated area, but whenever possible potatoes should be grown, since they give great assistance in keeping down weeds. After cropping the land for two or three years it is customary to sow out with grasses and clovers, but if climatic conditions are favourable, turnips, beet, and legumes like peas and beans, can be grown, and often yield exceedingly good crops. Barley and wheat are rarely successful on peat-land. The choice of seed is

important and the best results are usually obtained from seed grown on a peat-soil.

The physical characteristics of peat-soils render them particularly susceptible to frost, and in some districts late frosts cause much damage to crops. It has been observed that on land treated with potash the harmful effects of late frost are considerably reduced. The use of a light roller has also been found satisfactory in dealing with frost-action on grain crops.

It has long been recognized that peat-soils are naturally suited for hay and grassland, and numerous experiments have shown that they are capable of producing as good grass as most mineral soils. In addition, grassland is much less susceptible to frost-action than roots and cereals.

When sowing down in grass the best procedure is to roll the land with a heavy roller, and then to go over it with a light harrow before sowing; after sowing, the roller should again be used. No nurse crop is required. In spring it is usually found that a large number of annual weeds spring up before the grass, especially in areas which have been cultivated for some time, and the best means of eradication is to go over the land with a mower before the grass becomes too long. Low-growing weeds can be treated effectively with ground kainit, applied at the rate of 1½ cwt. per acre on a dewy morning.

*Recent work in Scotland.*—As mentioned above, some of the pioneer work on the improvement of peat-land was done in Scotland, but the vigorous campaign of reclamation which was going on a century ago has long since come to an end. This was perhaps partly due to the fact that some of the best and most accessible land was already reclaimed, but partly also to economic causes, such as the industrial revolution and the importation of large quantities of cheap foodstuffs from abroad.

Attention has been directed afresh to the problem in recent years by Mr. T. B. Macaulay, of Montreal, a Canadian of Scots extraction. With a view to assisting Scottish agriculture, particularly by improving the poorer classes of land, he made possible the establishment of an institute for soil research, consisting of laboratories at Craigiebuckler, near Aberdeen, and a demonstration farm on peat-land in Lewis. The island of Lewis has a total area of 683 square miles, of which only 18½ square miles are under cultivation. Apart from small stretches along the coast and a few patches of rocky mineral soil in the hilly regions, the island consists of moorland mostly of the creeping-moss type. The climate is humid, the annual rainfall being about 50 in., and the peat is largely derived from scirpus.

An area of 147 acres, forming part of Arnish Moor, near Stornoway, was selected as the site of the Macaulay farm, and operations were commenced in January 1929. Wooden box-drains were laid, and the preliminary cultivation was done with a modern moorland-cultivator with revolving steel knives; shell-sand, which is found abundantly in many places along the coast, was used as a source of lime.

It would be premature at this stage to draw many conclusions, but the following points may be noted.

1. Draining has been found difficult. This is partly due to lack of

experience of those carrying out the drainage work, but it is already obvious that the highly colloidal peat found in Lewis will be difficult to drain satisfactorily.

2. The surface of much of the peat in Lewis is very uneven, and in places there has been extreme erosion, with the result that it has been found difficult to use the moorland cultivator. The cultivator used has very broad wheels,of large diameter, but a machine fitted to a tractor of the caterpillar type would have been more suitable.
3. The importance of applying a sufficient quantity of lime (or shell-sand) has been demonstrated. The most marked response from fertilizers was obtained from phosphates, but it is obvious that potash and nitrogen are also essential.
4. Excellent pasture has been established on the virgin moorland by preparing a seed-bed with the moorland cultivator, applying shell-sand and artificial manures, and sowing out with a suitable grass-seed mixture. Various other crops have been grown successfully, but the best results have been obtained with hay and pasture.
5. On the drier parts, very promising results have been obtained in the establishment of pasture without cultivation, and with very little drainage. Shallow open drains were dug, shell-sand and farmyard manure (supplemented with artificials) were applied, and a grass-seed mixture was scattered over the surface. This procedure may prove useful for improving pasture-land where the surface is too uneven to use a cultivator.

The preliminary results obtained in Lewis indicate that by modern methods large tracts of more or less derelict peat-land can be improved. Many problems remain to be solved, but, where the need exists for additional land, attention can usefully be directed to the unutilized peat-mosses.

(*Received February 6, 1934*)

# OBSERVER'S BIAS IN SAMPLING-OBSERVATIONS ON WHEAT

F. YATES and D. J. WATSON

(*Rothamsted Experimental Station*)

In a set of experiments conducted at a number of different places it is frequently necessary to employ a different observer for each experiment. In such cases the interchange of observers is usually impossible owing to the expense involved. Anything, therefore, in the nature of a bias appertaining to any particular observer will not appear in the experimental error. In certain types of observation such bias may assume considerable magnitude. Any opportunity of comparing different observers should therefore be seized on and made use of, especially as such opportunities are often rare.

In March of this year a conference of the observers of what are somewhat anomalously known as the Wheat Precision Observations was held at Rothamsted. This conference provided just such an opportunity, and enabled an experiment to be made to determine to what extent the counts by various observers differed from one another, and how far this difference was constant for a given observer and consequently in the nature of a bias. A brief account of the results of this experiment may be of general interest and will be given here.

The outline of the Wheat Precision Scheme is as follows: Sampling observations on wheat, which it is hoped will extend over a series of years, are now in progress under the supervision of the Agricultural Meteorological Committee, acting for the Ministry of Agriculture and Fisheries and the Department of Agriculture for Scotland and the Meteorological Office. These observations are designed to determine the principal events which mark the progress of the wheat plant from germination to maturity, so that the effect of weather conditions, in combination with varying soil types, can be studied. Observations are conducted at a number of centres, eight in 1932–3, and ten in the current season, scattered throughout the south and midlands (with the exception of one in Scotland). The principal events determined are: (1) appearance above ground, (2) tillering, (3) emergence of ears, (4) when fit for cutting; quantitative measurements of the density and growth of the crop, and the final yield, are also taken. A full account of the results of the first year's observations has been given elsewhere [1].

In order to determine the various dates and quantitative measurements with accuracy a considerable observational technique has been evolved. It is not proposed to describe the technique in full here, but it may be mentioned that the sampling unit, on which all observations except those for appearance above ground are taken, is a set of four contiguous quarter-metre rows. Thirty-two such samples are observed at each date for each variety, two from each half of each of the eight plots of that variety, the positioning within the half-plot being random. A new selection is made at each date.

The conference was planned to take place when observations were being made for tillering. Date of tillering is arbitrarily defined as the date at which the ratio of shoots (including the original shoot) to plants reaches the value of 2 : 1. It is determined by making counts for both plants and shoots at four weekly intervals, two before and two after this ratio has been reached, the actual date being ascertained by interpolation by means of the best fitting straight line. It will be realized that considerable judgement is required to determine what is in fact a separate plant, and what a tiller, particularly if the plants are crowded.

The actual test was planned for ten observers. Ten sampling units were marked off on a suitable piece of wheat and each of these sampling units was counted by all observers. The order of counting was determined by a Latin-square arrangement, so that each observer had a definite non-clashing order assigned to him.

Unfortunately the arrangement broke down in two particulars. Newport II observer mistook the instructions and observed his plots in the wrong order (the different rates of counting by the different observers explained why this mistake was not immediately discovered) and Rothamsted put forward a composite observer in the shape of three individuals. Fortunately neither of these errors has seriously disturbed the analysis of the results. Apart from these mistakes the observations were satisfactorily carried out. At the end of the experiment the plants were dug up by hand and plants and shoots of each quarter-metre counted.

TABLE 1. *Discrepancies in Counts of Plants*

| *Observer* | *Sampling Unit* 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plumpton | $-4^{3}$ | $-9^{4}$ | $-2^{8}$ | $0^{6}$ | $-1^{7}$ | $-10^{1}$ | $+1^{10}$ | $-4^{5}$ | $-4^{9}$ | $+2^{2}$ | − 31 |
| Long Sutton | $-3^{6}$ | $-10^{2}$ | $0^{9}$ | $-4^{1}$ | $0^{3}$ | $+2^{5}$ | $+2^{7}$ | $-2^{10}$ | $-9^{4}$ | $+6^{8}$ | − 18 |
| Cirencester | $-8^{9}$ | $-18^{2}$ | $-8^{8}$ | $-5^{10}$ | $-10^{5}$ | $-9^{8}$ | $-11^{6}$ | $-12^{4}$ | $-21^{1}$ | $-6^{7}$ | − 108 |
| Boghall | $-4^{5}$ | $-5^{6}$ | $0^{10}$ | $+1^{5}$ | $+2^{8}$ | $-7^{2}$ | $+3^{9}$ | $-8^{3}$ | $+5^{7}$ | $0^{4}$ | − 13 |
| Newport II | $0^{10}$ | $-8^{9}$ | $0^{8}$ | $+1^{4}$ | $+1^{1}$ | $-2^{8}$ | $+5^{3}$ | $-1^{7}$ | $-1^{2}$ | $+4^{5}$ | − 1 |
| Seale-Hayne | $-14^{10}$ | $-22^{9}$ | $-15^{8}$ | $-16^{3}$ | $-15^{1}$ | $-16^{7}$ | $-19^{4}$ | $-14^{5}$ | $-30^{5}$ | $-15^{2}$ | − 176 |
| Newport I | $-4^{9}$ | $-9^{10}$ | $-2^{5}$ | $-4^{2}$ | $0^{9}$ | $-4^{4}$ | $-5^{1}$ | $-4^{7}$ | $0^{3}$ | $-3^{6}$ | − 35 |
| Woburn | $-10^{7}$ | $-11^{1}$ | $-10^{4}$ | $-6^{9}$ | $-4^{3}$ | $-11^{6}$ | $-12^{5}$ | $-7^{2}$ | $-18^{8}$ | $-6^{10}$ | − 95 |
| Wye | $-17^{3}$ | $-10^{5}$ | $-10^{1}$ | $-2^{7}$ | $-2^{4}$ | $-6^{10}$ | $-8^{2}$ | $-4^{8}$ | $-17^{6}$ | $-2^{9}$ | − 78 |
| Rothamsted | $-2^{4}$ | $-6^{7}$ | $-1^{2}$ | $+2^{8}$ | $+1^{6}$ | $-1^{9}$ | $+2^{3}$ | $-7^{1}$ | $-5^{10}$ | $+6^{5}$ | − 11 |
| Mean | − 7 | −11 | − 5 | − 3 | − 3 | − 6 | − 4 | − 6 | −10 | − 1 | − 58 |
| True Value | 54 | 70 | 43 | 50 | 54 | 65 | 61 | 58 | 74 | 56 | 585 |

The small figures indicate the order of the observations.

*Time Means*

| Time: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean: | 50·2 | 52·0 | 52·4 | 51·9 | 52·6 | 52·0 | 54·7 | 54·1 | 54·5 | 54·0 |

Table 1 shows the discrepancies in plant-count of the individual observers. Inspection of the table immediately indicates that there is a strong negative bias in most of the observers, and that this bias differs from observer to observer and also from sample to sample. Inspection of the discrepancies of the individual quarter-metres (not shown here) shows, even more clearly than the totals of the samples, that this negative bias is most pronounced where the plants were most dense. This is of course

to be expected. It is noticeable, however, that the under-estimation of the more biased observers is not confined to the more congested samples and is not disproportionately great on such samples.

The mean discrepancies of times of observations 1 to 10 are shown at the foot of Table 1. In these means the discrepancies of Newport II are allotted to the times at which the observations should have been made, and not to the true times; the time means are thus estimates of time-differences unbiased by observer or sample differences; the fact that the times of Newport II were not the true ones will merely produce a slight watering down of the time effect, if any.

TABLE 2. *Analysis of Variance: Plant-counts*

| | *Degrees of freedom* | *Sum of squares* | *Mean square* |
|---|---|---|---|
| Sampling units . . | 9 | 818·64 | 90·96 |
| Observers . . | 9 | 2851·44 | 316·83 |
| Times { Regression . | 1 | 140·12 | 140·12 |
| Times { Remainder . | 8 | 46·52 | 5·82 |
| Error . . . | 72 | 759·72 | 10·55 |
| *Total* . . . | 99 | 4616·44 | |

The full analysis is given in Table 2. Time-effects are established as significant on considering the linear regression of the ten values. The observers themselves attributed this time-effect as the sorting out of the shoots by the earlier observers, so that the plants were more easily distinguishable. The fact that no such effect was observed on the shoots indicates that this is probably the true explanation.

It is not considered that the two mistakes already alluded to have seriously disturbed the analysis. The time-effect is not sufficiently large for the mistake of Newport II to produce appreciable bias in the sample or observer means and there appears to be little difference between the three Rothamsted observers.

TABLE 3. *Shoot-counts*

| Observer: | Pl. | L.S. | Cir. | Bog. | N.II | S.H. | N.I | Wob. | Wye | Roth. |
|---|---|---|---|---|---|---|---|---|---|---|
| Count: | 707 | 723 | 701 | 711 | 693 | 682 | 707 | 669 | 682 | 695 |

Mean: 697. By digging: 755.

The total shoot-counts of each observer is given in Table 3. Here also there is a serious under-estimation of the true value as determined by digging, but there is much less variation between the different observers. The under-estimation is here presumably due to the fact that some of the shoots counted on digging had not fully made their appearance above ground, though on the count by digging shoots that had clearly not made their appearance were not counted.

In the analysis of variance of shoot-counts (not reproduced) the differences between observers reach the 5 per cent. level of significance, but time of observation shows no effect. The residual variance, 10·0, closely approximates to that of the plant-counts.

Since the counts are taken with the object of determining the ratio of

shoots to plants it is of interest to see how far this ratio is affected by the counting errors. Inasmuch as the errors of counting may to a certain extent be compensating, low plant-counts being associated with low shoot-counts (though this does not occur to any great extent), the ratio for the various observers will be the quantity to examine. Table 4 shows

TABLE 4. *Ratio, Shoots: Plants*

| Observer: | Pl. | L.S. | Cir. | Bog. | N.II | S.H. | N.I | Wob. | Wye | Roth. |
|---|---|---|---|---|---|---|---|---|---|---|
| Ratio: | 1·28 | 1·28 | 1·47 | 1·24 | 1·19 | 1·67 | 1·29 | 1·37 | 1·35 | 1·21 |

Mean: 1·335 Estimated: 1·214

this ratio. Assuming that there are 710 'visible' shoots the true ratio is 1·214. The mean ratio of all observers is 1·335, giving a mean bias of 0·121. The variance about this mean is 0·02063, giving 0·144 as the observer's standard error. The distribution is decidedly skew, half the observers obtaining ratios between 1·19 and 1·29 whereas the other half are all greater than 1·29, the worst being 1·67. It should be remembered, also, that the conditions of observing cause this bias to be underestimated, since all times have been included and it has been shown above that the bias was reduced as the observations progressed. In practice each sampling unit is observed once only. The mean ratio of the first set of observations, 1·39, may consequently be regarded as a better value from which to estimate the mean bias. This gives a mean bias of 0·18, nearly twice the value obtained above.

It is, of course, doubtful how far the bias of any particular observer remains constant. Probably it is fairly constant for plants and shoots of a given density on the same soil type, but it may quite probably increase very considerably as the density of shoots increases. The conditions of the experiment in one respect were particularly easy, as the ratio of shoots to plants was still low. The plant number, 1,872 per 32 metres, on the other hand, was high, compared with last year's values, which at tillering ranged from 368 to 1,578 per 32 metres. This was partly because thinly populated areas were avoided in selecting the samples for observation.

The average rate of tillering last year was about 35 tillers per 100 plants per week. Assuming that the bias of each observer is constant this would indicate that the bias of the worst observer introduced an error of about nine days in the date of tillering, whereas the best observers had little or no bias. Since the last four stations to tiller last year tillered within an interval of a fortnight, errors of this magnitude cannot be regarded as by any means negligible. It is hoped, however, that a few actual counts by observers on subsequently dug samples will serve to eliminate such large bias as that of the observer from Seale-Hayne. As a result of this experiment this practice is now to be explicitly recommended.

## REFERENCE

1. Wheat Precision Observations. J. Min. Agric. 1933, **39**, No. 12, 1082–4; **40**, No. 3, 206–8; No. 7, 591–3; No. 10, 903–6.

(*Received March 27, 1934*)

# SOIL SURVEY OF NORTH SHROPSHIRE[1]

## *Pt. I.* GEOGRAPHY, GEOLOGY, PARENT MATERIALS, SOILS

W. MORLEY DAVIES and G. OWEN

(*Harper Adams Agricultural College, Newport, Shropshire*)

*Introduction.*—The area described in this report forms the southern section of a considerable plain which includes, besides North Shropshire, parts of the surrounding counties of Flint, Cheshire, Derbyshire, and Leicestershire. The plain has no well-defined limits on the north, east, and south, but on the western side the hills of Wales and South Shropshire form a natural boundary. Several distinct types of husbandry are practised in this area of 192 square miles. In earlier times, when agriculture was probably more stable than it is to-day, two main forms of husbandry could have been traced: on the eastern side, fattening, combined with mixed farming; and on the western side, dairying, inclusive of cheese-making and the sale of liquid milk. Recently, under the stress of hard times, milk-production has undoubtedly spread to the east and is carried on with apparent success in districts remote from the typical grasslands. Beef-production is still an important industry and is carried on despite very meagre profits. In earlier times agricultural utilization was doubtless determined solely by natural soil fertility, but now even soils that were once regarded as poverty-stricken can be profitably farmed, thanks to the improvements brought about by an increased understanding of their manurial needs.

Supporting this rather mixed agriculture is a collection of soils varying in type from light blow-away sands to the heaviest clays, with about every conceivable intermediate variety. This complexity is the result of not one, but of several ice-streams superimposed on a pre-existing surface which was itself probably rather complex; and Post-glacial changes have added to this complexity. In attempting a comprehensive study of the soils of the area it is therefore essential to obtain a clear picture of its geology.

Modern methods of studying soils in the field demand attention not only to geological characters, but also to soil-forming factors such as weathering, drainage, and vegetation. The way in which these characters are grouped determines the nature of the now familiar soil unit, the series. In Part II of this report it will be shown how variations in these groupings lead to the differentiation of the various series found in North Shropshire.

### *Geography and Climate*

The elevation of the plain varies from 200 to 300 ft. above sea-level. This general level is broken by a series of low hills rising in crescent formation and composed of sandstones harder than those underlying the adjacent country. This chain of hills adds appreciably to the picturesqueness of the scenery; from west to east it includes Nesscliffe Hill, Pim Hill,

[1] Published for the Excursion Committee of the Third International Soil Congress, 1935.

Myddle Hill, Grinshill, and terminates in the highest land of all, 674 ft., in Hawkstone. There are few rivers and they are mostly meandering and sluggish. The chief is the Severn, which touches only twice on the fringe of the area, once in the form of a loop almost encircling the Isle near Shrewsbury, and again at Pentre some distance to the west. The remainder are the Roden, Tern, Perry, Meese, and Strine, and of these none rises in the area surveyed. The Roden, Meese, and Strine all flow into the Tern which, as well as the Perry, flows direct into the Severn. The nature of the country through which these rivers flow has favoured the formation of considerable tracts of alluvium. The industries of the plain, other than agriculture and forestry, are few and chiefly concerned with the production of building materials.

The average rainfall varies between the close limits of 25 and 27 inches.

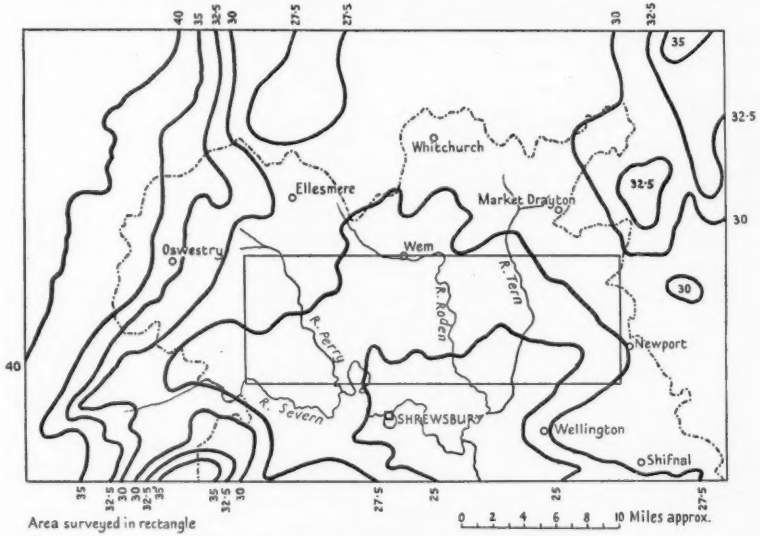


FIG. 1. Average annual Rainfall in inches, North Shropshire and District.

A rainfall map of the area, based on the averages of twenty-five years, is shown in Fig. 1, for which the writers are indebted to the Director, Meteorological Office of the Air Ministry. The average maximum temperature for the ten years 1924 to 1933 is 56·0° F., the average minimum temperature is 41·3° F. and the average mean temperature 48·6° F.

## *Geology*[1]

The underlying rocks are predominantly Triassic and, being composed of marls and sandstones, naturally give rise to a diversity of soils very

[1] The writers wish to acknowledge their indebtedness to the following valuable memoirs of H.M. Geological Survey: (*a*) the Country between Wolverhampton and Oakengates, (*b*) the Country between Stafford and Market Drayton, and (*c*) the Geology of the Country around Wem.

variable in texture. The nature of the superficial materials, however, does not always depend on the underlying rocks, but on the presence of much drift of Glacial origin, which probably proceeded from several directions. The following list attempts to present in more detail the geological sequence of the rocks and superficial deposits found:

*Superficial Formations*

| | |
|---|---|
| Recent and Post-glacial | Peat. |
| | Fluvio-glacial Gravels. |
| | Alluvium and River Terraces. |
| | Laminated Clays. |
| Glacial | Boulder Clays. |
| | Sands and Gravels. |

*Solid Formations*

| | |
|---|---|
| Keuper | Keuper Marl (including thin bands of sandstones, 'skerries'). |
| | Keuper Sandstone. Waterstones and yellow freestones. |
| Bunter | Upper Mottled Sandstone, usually red, medium to fine grained. |
| | Pebble Beds, coarse red sand grains and pebbly. |
| | Lower Mottled Sandstone, usually red, coarse to fine grained. |
| Carboniferous | Upper Coal Measures. Keele and Enville Beds, red marls and sandstones. |
| | Carboniferous Limestone Series (Lilleshall). |
| Cambrian | Comley Sandstone (Lilleshall). |
| Pre-cambrian | Longmyndian Series, greyish green shales and sandstones in Haughmond Hill. |

*Outcrops*

Intrusive Igneous Rocks. Dolerite (Lilleshall).
Cambrian, Comley Sandstone (Lilleshall).
Carboniferous Limestone Series (Lilleshall).

These three relatively small outcrops occur on the extreme eastern side of the area in and near the village of Lilleshall. Their contribution to direct formation of soils is unimportant, but they have probably influenced the soils in their immediate neighbourhood. The Limestone Series, now represented by old and disused workings in the Carboniferous Limestone, were once of great agricultural significance because they supplied lime to all the surrounding country. Unfortunately the kilns had to be closed on account of the practical difficulties presented by deep workings.

*Pre-cambrian.*—Pre-cambrian rocks outcrop on the extreme southerly border in Haughmond Hill (cf. Fig. 1). They consist mainly of grey and green sandy shales, purplish sandstones, and conglomerates. The associated soils tend to be greyish brown and to contain a fairly high

proportion of sand, of which rather more than half is fine sand. Whilst these rocks, in their shaly phases, have given rise to silt soils of the Powys suite in other localities, they have not done so here. As they occur on a slight eminence, their influence is discernible in the soils of the immediate neighbourhood.

*Upper Coal Measures.*—The most important beds of the Carboniferous system are associated with the Upper Coal Measures, and are designated Keele and Enville Beds. In the older maps these were shown as Permian, but more modern work on their palaeontology would refer them to the Carboniferous. For the most part they consist of red marls, with sandstones and breccia. The soils to which they give rise are characterized by their strong purplish-red colour, a feature which makes them conspicuous, particularly when wet, even in a country-side where red soils predominate. Their alternating beds of marls and sandstones give rise to rapidly changing soil characters and render mapping in a featureless country rather difficult.

Although these rocks underlie considerable tracts of country, they seldom emerge at the surface; nevertheless their influence cannot be unimportant, since they contribute to, and constitute many of, the subsoils. The beds occur at Lilleshall, Hinstock, Stoke-on-Tern, Ollerton, and Walton. In neighbouring areas they are important contributors to the soils.

*Triassic rocks.*—The area under review, especially in the east, is essentially Triassic. This is evident both in the nature of the Glacial and Post-glacial deposits as well as in the sedentary material. In a manner similar to that cited above the Triassic Rocks are largely overlain by drift material and emerge in certain areas only. Not unnaturally, these points of emergence are mainly found in the higher land and give rise to the well-known sandstone hills of North Shropshire.

A study of the 'solid' geological map of the Wem district will show that the Lower Triassic Rocks, as typified by the Bunter Beds, occur in the south-east part of the area, whilst those of the higher Triassic Rocks, the Keuper, occur in the north-west. Their line of contact occurs approximately along the diagonal bisecting the map.

*The Bunter Beds.*—These beds are represented by all three divisions, the Upper and Lower Mottled Sandstones and the Pebble Beds, the first two of which are brownish-red sandstones, with a little dull grey mottling. The red colour appears to be due to a superficial coat of iron oxide, which also serves as cementing material for the rounded grains of silica. The intensity of cementation is reflected by the way in which the rock weathers. On the whole, the most strongly cemented (and therefore hard) beds are coarsely gritty; the fine-grained beds are seldom hard. A deep cutting through the beds, such as occurs near Preston Brockhurst, reveals much false bedding. The degree of hardness of these rocks is important in relation to soil formations. As would be surmised, hard rocks usually give rise to shallow soils, which present difficulties in cultivation and cropping that seldom arise on the deeper and better soils occurring on the softer beds.

The Pebble Beds must be regarded somewhat differently from the

Upper and Lower Sandstones. On the whole they are more highly porous and, when occurring in higher land, are very difficult to farm. When they occur in featureless country they differ little, except in their content of pebbles, from the adjacent beds, and from the soil point of view are classified together. Their greater resistance to the passage of the older types of agricultural implements was most probably the chief reason why they remained uncultivated common land. There is no doubt that the beds of the Bunter have largely contributed to the materials forming the lighter elements of the Glacial Drift.

*The Keuper Sandstone.*—In this area there is no well-defined line of demarcation between the highest beds of the Bunter and the lowest of the Keuper Sandstone; one apparently merges into the other, since there is no distinctive colour change at the point of junction, as is observed in some districts.

The Grinshill and Ruyton Sandstones, as the junction beds are called, are of economic importance as they supply the well-known Grinshill freestone, which has been used for building and other purposes since the earliest times. The yellow-grey sandstones of Myddle give rise to characteristically greyish sandy soils. Texturally they are not very dissimilar from the soils of the Bunter. A curious characteristic is the occurrence at various points in the subsoil of considerable quantities of finely divided manganese dioxide, which have resulted from the weathering of highly manganiferous sandstone rock. These sandstones are succeeded by the series known as the Waterstones, consisting of interbedded marls and sandstones and presenting considerable difficulties in classification and mapping. They occur at Hodnet and Marchamley, where they give rise to distinctive soils.

*Keuper Marl.*—The beds forming the Keuper Marl are exposed in only a few localities, and are to be seen near Preston Brockhurst, Shooter's Hill, and Clive. The soils to which they give rise are brownish red, heavy in texture, seldom acid, and usually under grass. Inter-bedded with the marls occur thin seams of sandstone, called 'skerries'. Although these beds only give rise to relatively small undrifted areas, their influence is both considerable and widespread, since the materials forming them have contributed largely to the composition of the glacial drift. The greyish-green bands so characteristic of the Keuper Marl in other districts appear infrequently in this area.

*Boulder Clay, Sands, and Gravels.*—Of all the geological ages there is no doubt that the Glacial and Post-glacial periods are the most important, and have imprinted their effects more strongly than any other on the soils of the district. The area appears to have been subjected to the effects of two main, but not necessarily synchronous, ice-streams. One came from the north and originated in the Lake District and South Scotland; the other from the high land near and around the Arenig in North Wales. The former stream, besides bringing in material from Scotland, the Lake District, Lancashire, and Cheshire, probably swept round and included material from the floor of the Irish Sea; the latter stream scraped up and brought in material chiefly from the west. No definite order can be traced in the drift deposits except that the Welsh appear to have over-

stepped the northern Triassic drift on a line extending roughly from Ellesmere to Shrewsbury. Probably the influence of the northern ice-stream had been well established before the arrival of the Welsh ice. The junction is indicated not only by a change in the nature of the material but also by the occurrence of a remarkable line of moraines, well developed around both Ellesmere and Shrewsbury. The waters imprisoned between these mounds have persisted to the present day and contribute to the picturesque character of the county.

A closer examination of the materials carried by the ice reveals the interesting fact that, although many of the boulders have undoubtedly been carried far, most of the finer material or matrix is of local origin.

Whenever the drift from the north is examined, although containing Scottish and Lakeland boulders, it appears to consist for the most part of material derived from Triassic Rocks. The heavier parts would appear to have been contributed largely by the Keuper Marl and the lighter by the Triassic Sandstones. Evidence supporting this view is deducible from many data, such as the presence of calcium carbonate in the Boulder Clay, similarity in composition of the clay fractions, lithology, colour, &c.

The Welsh Glacial drift shows similar variations from heavier to lighter materials, although within a somewhat more restricted range. From a knowledge of the types of Welsh shale rocks (as typified by the pebbles and boulders present), it would be expected that the silt fraction of the soil derived therefrom would be a dominating fraction of the mechanical analysis. This is so only in the heavier soils, although it must be admitted that even the Glacial sands and gravels are seldom as light and porous as in the northern drift.

The unbedded stony drift and boulder clays usually give rise to low-lying land and featureless slopes, whilst the gravels and sands form the higher hummocky ground. The depth of the Glacial-drift deposits varies considerably from place to place and is related, among other things, to the nature of Pre-glacial topography. On the whole, the deposits increase in depth and area towards the west, but it must be made clear that this is only a rough generalization.

Everywhere the area is studded with marl pits; they are so numerous and in places so extensive that, if the erstwhile habit of marling is the sole reason for their existence, the practice must have brought about changes in the soil that have persisted to the present day. That this is so is verified by analytical figures obtained on some of the lighter soil series.

*Fluvio-glacial Gravels.*—These consist of bedded sand and sandy gravels, which from the soil point of view can be compared with Glacial Sands and Gravels. They occur widely but irregularly.

*Alluvium.*—This material, deposited in the flood plain of the rivers, covers considerable areas. The most important is the alluvium of the Severn, which is so uniform that it gives rise to a well-defined soil series. The alluviums of the smaller rivers, although extensive in the aggregate, give rise to less clearly defined soils not distinguished by definite names.

*Laminated Clays.*—These occur in the vicinity of Edgmond, Adney, and Kinnersley. Their occurrence is associated with the former existence

of Post-glacial lakes, in which they were laid down. In some places, e.g. on the Harper Adams Agricultural College Farm, they are of small extent. In other places, where they are more extensive, they are associated as marginal beds, surrounding extensive areas of fen peat.

*Peats.*—These are exclusively of the 'fen' or mild type, having been laid down for the most part in shallow Post-glacial lakes into which lime-bearing waters drained. They reach their maximum extent in the Weald and Birch Moors, parts only of which occur in the area under review. Elsewhere in the district there are numerous patches of peat, but there are only two areas of any consequence, viz. Baggy Moor and a low-lying area near Loppington.

### *Parent Materials*[1]

Although the various rocks mentioned above would until recently have served as a basis for classifying the soils, modern pedology demands the grouping or subdivision of the geological beds, chiefly on the grounds of lithology, into Parent Materials. Thus, from the soil point of view, such beds as the Bunter Sandstone, the Glacial Sands, and the sandy phase of the Keele Beds are conveniently grouped together into the class of Parent Materials known as the Red Sands and Pebbly Red Sands. On the other hand the subdivision of the Keele and Enville Beds is made by placing their marly phase in the parent materials, the 'Red Marls'. This does not mean that the individuality of the soils arising from these beds is lost, but rather that their common characters are more clearly shown up by classifying them as members of one group. Their differences are still preserved in the further subdivision of soils, the 'series'.

On this basis, therefore, the following nine parent materials[2] are distinguished in the area under consideration:

Grey and Black Shales and Grits.
Red Sands and Pebbly Red Sands.
Red Marls.
Red Clay—Sand Drift.
Yellow Sands.
Mixed Drift.
Silt-Clays.
Alluvium.
Peat.

### *Soil Development*

Detailed study of the soils reveals the fact that any particular parent material can, under the influence of various soil-forming processes, give rise to one or more members of the recognized world groups. The groups represented appear to be as follows:

*Soils developed under conditions of free drainage.*—Two main groups are distinguishable, podsols and brown earths. The former group is characterized by the downward movement of weathering products and their subsequent deposition in layers that are distinctive and typical.

[1] This classification follows that of the First and Second Reports of the Soils Correlation Committee 1931 and 1933.

[2] Twenty-six parent material groups have so far been distinguished in Britain.

The brown earth is a soil whose profile shows no marked differentiation into layers. It is characterized by a uniform distribution of silica and sesquioxides throughout the weathering material, and the presence of a brown or modified brown colour.

In each of these main groups it is necessary to distinguish two ecological conditions; one, where a natural covering of vegetation is found, and the other—which has often produced far-reaching effects—where crops grow under cultivation.

*Free-drainage soils carrying natural vegetation.*—In this area these soils are mostly of sandy texture and have developed on a parent material poor in bases. Pebbles may be entirely absent, or present in varying quantities, and, generally, the more frequently the pebbles occur the poorer the soil. It is customary to find such soils either under heath with the usual plant association (*Erica cinerea*, *Vaccinium myrtillus*, bracken and fescues) or under a heath scrub-oak and birch association. In either case the soil is a well-developed podsol. It is interesting to speculate whether such soils have ever carried deciduous forest, as many ecologists assert. Their poverty in natural bases suggests a negative answer, and, if this is so, then the heath might be regarded as being the primitive association which gave rise to an ancient podsol. If, on the other hand, deciduous forest were the primitive association, then the podsol might be regarded as having developed comparatively recently from the degradation of a brown earth following removal of the trees.

*Free-drainage soils under cultivation.*—Two extreme conditions exist, the first in which the soil is, except for a slightly darker top soil, undifferentiated into horizons and can be regarded as brown earth. This condition is observable over wide areas and is found mostly in the lighter soils, where little resistance is offered to percolation. The second condition is that of a cultivated podsol with the 'pan layer' more or less intact, depending on the length of time that cultivation has been practised. Plate 3a illustrates the type of country in which these soils occur.

Between these two extremes all degrees of variation are found. There is ample evidence that the cultivation of a podsol sets in motion a process of 'depodsolization' with the ultimate production of a brown earth. The changes involved in this process cannot be discussed here, but it may be pointed out that the process is not entirely due to the breaking up and mixing effect of mechanical treatment.

The condition of the soil profile cannot be regarded in any way as being static, but rather moving from one condition of temporary equilibrium to another, as determined by the nature of man's interference. In this highly cultivated country, therefore, the present state of the soil is in part a reflection of past treatment.

The effect of cultivation varies somewhat according to the nature of the topography. In an undulating country removal of an anchoring heath-vegetation is rapidly followed by erosion. In this case, where the soil is podsolized, the A horizon is frequently washed into the hollows, where it forms an addition to the existing A horizon, while the B (iron pan) horizon remains exposed on the higher ground. Such a condition results in a patchwork of brown and greys, seen frequently in certain

localities. The accumulation of a deep A layer has the effect of preserving (by being deeply buried) the characters of the original podsol.

In a flat country the changes in the character of the profile are slower and depend on chemical rather than mechanical factors.

*Soils Developed under Conditions of Impeded Drainage. Meadow Soils*

These soils are characterized by and develop in the presence of excess of water. Two conditions must be recognized: the first, where the water-table lies at or near the surface, and the second, where impedance is due to an impervious stratum at some lower point in the profile.

*Natural soils with high water-table.*—These soils are almost continuously submerged and bear a flora of aquatic plants resulting in the formation of fen peat (developed under anaerobic and neutral conditions). Consequently their uses are extremely limited and they are fit only for growing osiers. Improvement consists in drainage.

*Drained soils with a natural high water-table.*—These soils when drained are found to consist mainly of organic matter. In a peat soil the depth will depend on the length of time of accumulation, the nature of the plants composing it, and the time which has elapsed since it was drained. Such conditions occur in several localities, particularly in the Birch Moor, the Weald Moors, and Baggy Moor. Another instance is found on the alluviums bordering the sluggish streams of the area, where the surface soil is almost invariably highly organic and overlies a bleached subsoil. The bleached condition is characteristic and may be due to a combination of iron reduction and silica accumulation.

*Natural soils with impedance due to impervious layers.*—If it had been possible to examine the soils of North Shropshire prior to interference by man, there is no doubt that extensive areas would have been found in which an impervious layer in the soil resulted in extreme conditions of impedance, giving rise to a definite and characteristic vegetation. It is probable that two conditions of plant association existed, one that could be described as wet woodland, and the other as wet meadow. At the present day, since drainage has altered natural conditions so considerably, it is impossible to estimate the relative importance of the two classes. At present a few areas of woodland occurring on wet impervious soils are found. These are partly drained with surface gutters and, in addition to quite well-developed trees, carry a semi-aquatic ground flora (*Aira*, *Juncus*, *Carex*, &c.). In some localities, wet grassland occurring on soils of an impervious character is seen, although such areas are few.

*Drained soils with impedance due to impervious layers.*—The majority of the soils whose impedance is due to impervious layers are artificially drained. There is no doubt that the full significance of this drainage is hardly realized. Without it vast low-lying areas would be largely covered with rushes, and unusable in the wetter seasons. When the impervious layer is at or near the surface the land is invariably down to grass, as in Plate 3 (*b*), where a typical marl pit is also shown. When deeper, arable cultivation may be possible. The top-soil is characterized by a high content of organic matter (loss on ignition 10–14 per cent.), a feature not observable in the lower layers.

(*a*) TYPICAL BUNTER SANDSTONE COUNTRY, CHENEY HILL

(*b*) HEAVY TRIASSIC BOULDER CLAY GRASSLAND WITH MARL PIT

The level of the water-table fluctuates with variation in rainfall and this results in a horizon of alternating conditions of oxidation and reduction. The production of the characteristic mottling seen in this horizon is due partly to the reason stated, and partly to the deposition of concretionary manganese dioxide.

### *Detailed Classification of the Soils of the Area*

By common consent the series is regarded in this country as the soil unit. The series may be described as including a set of soils derived from the same or similar parent materials, formed under the same conditions, and showing a general similarity in the profile.[1] Subdivision of the series into types is made more particularly for technical purposes and is based on variation of the texture of the more superficial material.

In Table 1 is shown the relationship of world groups, parent material, and series. It will be noticed that a parent material may occur in more than one world group giving rise to a different series. This is the result of the operation of a different set of soil-forming processes.

TABLE 1.—*Soils with Free Drainage*

| *World Group* | *Parent Materials* | *Mode of formation of Parent Material* | *Series Name* |
|---|---|---|---|
| Podsols | Red sands, pebbly red sands and yellow sands | Straight and drift | Goldstone (1) Crannymoor (2) |
| Brown earths | Red sands | Straight | Bridgnorth (2) Shifnal (1) Hodnet (3) |
| | | Drift | Newport (2) |
| | Red marls | Straight | Lilleshall (1) |
| | Grey and black shales and grit | Straight | Haughmond (1) |
| | Mixed drift (red sands and grey shales). | Drift | Baschurch (4) |
| | Yellow sands | Straight | Clive (3) Leaton (1) |
| | *Soils with Impeded Drainage* | | |
| Meadow soils | Grey and black shales | Drift | Cegin (6) Conway (6) Albrighton (5) |
| | Red marls | Straight | Worcester (1) |
| | Red clay-sand drift | Drift | Wem (3) Roden (1) |
| | Mixed drift (trias and grey shales) | Drift | Aber (5) Whittington (2) |
| | Silt clay | Lacustrine | Strine (4) |
| | Peat | | Peat (series undifferentiated) |
| | Mixed and alluvium | | Mixed and alluvium (series undifferentiated) |

From the table it will be seen that no differentiation of peats and mixed alluvium into series has been attempted. This, in the former case, is on account of insufficient data, and in the latter owing to the impossibility of making satisfactory divisions in such mixed materials. Including these two cases, 24 series have been recognized. The number of types distinguished within each series is shown by the figures in brackets; 13 series do not include more than 2 types, and in each of the remaining 9 series the number of types varies from 3 to 6.

[1] This description is given by G. W. Robinson, D. O. Hughes, and Brynmor Jones in Progress Report of Soil Survey of Wales, 1927–1929, *Welsh Journal of Agriculture*, 1930, **6**, p. 249–50.

Summarizing, it will be seen that 3 world groups, 9 parent materials, 24 series, and 17 types are distinguished.

*Mapping*.—With the exception of a short period spent in reconnaissance, mapping has always been carried on concurrently with classification in this area. The basis for field work is the Ordnance Survey 6-inch sheet. Mapping is pursued on a field-to-field basis, and series and types are delineated by boundary lines. Colouring of the sheets is carried out according to the method laid down in the Soil Survey Paper No. 37.[1] The series is regarded as the unit and the relationship existing within groups of series arising from one parent material is shown by a similarity of colours used. The maps have been reduced to a scale of one inch to the mile.

In addition to the series and type boundaries, the maps carry numerous symbols to show such accessory data as variations and direction of changes in topography, degree of wetness, stoniness, &c.

[1] Soil Survey Paper No. 37. Suggested scheme for colouring and the use of symbols on soil-survey maps. W. Morley Davies and G. Owen, May, 1933.

(*Received March 24, 1934*)